DESIGN GUIDELINES FOR

Sustainable Biological Field Stations

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PURPOSE

The main purpose of this design-oriented manual is to provide planners, designers, and managers of biological field stations and marine laboratories with guidance to help them make well-informed and sound decisions about the design of new stations or about possible retrofits of existing ones.

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CREDITS

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NOTICE

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Available electronically at the website of the Organization of Biological Field Stations (OBFS), http://www.obfs.org

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PREFACE

Designing sustainable structures in North America has emerged as a mainstream priority for architects. This visible change has increased as energy, water, and building material costs have escalated and the tolerance for poor building environments has decreased. The rise in Leadership in Energy and Environmental Design (LEED) certified buildings in North America also indicates that the priority of sustainable buildings has gained momentum from the mainstream business and public sector of our civilizations.

However, we must also better understand the recent historic evolution of building design on our continent. Early European settlers who moved to what is now Canada, the United States, and Mexico, brought their traditional building design and construction techniques, but they also were astutely aware of native building structures and the use of locally available materials. The selection of building locations was paramount to surviving the first few years of settlement when maximizing sunlight exposure during cold winters, minimizing the distance to streams, springs, or wells for obtaining fresh water, and maintaining adequate supplies of food and fuel consumed most of the settlers waking hours. As the infrastructure of new villages, towns, and cities grew, the awareness slowly waned for natural resources with whom early settlers were so tightly linked. As low-cost electricity became readily available, the importance of building location and design attributes became more a factor of style, choice, and aesthetics, than of necessity and conservation. However, as the cost and scarcity of fresh water, fuel, and food has increased in recent years, attention has refocused on building design and construction choices that can maximize the use of readily available resources and minimize the need for electricity and fuels.

Designing and retrofitting structures to improve their sustainability has emerged in the North American “green movement” and has garnered both scientific and market support. The recent increase in developing rooftop gardens in Chicago that was led by Mayor Richard M. Daley is just one example of an environmentally sustainable building practice that improves quality of life and reduces building energy costs and surface water runoff. Ultimately, the decision to incorporate sustainable building design and construction attributes depends upon balancing the often higher initial construction costs with the long-term savings in building operating and maintenance costs.

Field stations and marine laboratories have the additional challenge to be sustainable since they often are located in more rural and sometimes remote locations where access to architects, contractors, and suppliers of sustainable expertise and materials may be limited. This may require some additional time and effort up front to locate expertise. However, field stations and marine laboratories also have the enviable position of serving as positive examples and leaders of sustainable building practices in their regions and therefore may be able to justify the extra effort when a structure is being built or retrofitted. Field stations and marine laboratories may be able to distribute their knowledge and “pay it forward” with expertise that allows other regional building projects to save natural resources and funding.

This manual provides details on the number one consideration for long-term building sustainability - structure location. This single decision will impact transportation cost for building materials, long-term energy consumption, loss of current habitat to building footprint, ability to incorporate solar and/or wind collection in the site plan, and overall site plan aesthetics. Site selection will determine the ability to incorporate other sustainable options in the structure as the new design or sustainable retrofit evolves and as new technologies emerge in the future.

Long-term considerations for minimizing the carbon footprint of the structure involve the choice of building materials (new or recycled), source and quantity of fresh water and the treatment of the used water stream, and the electrical and/or fuel source for the structure. In some cases, remote locations or heavy seasonal fluctuations in use of field station or marine laboratory facilities may necessitate petroleum-based fuels to supplement sustainable fuel sources. However, the secret to long-term affordability and predictability of operating costs is to incorporate sustainable power sources into the initial design or retrofit.

Ultimately, the objective of sustainable building design is to minimize the waste stream from the construction, operation, and maintenance of the facilities. This includes minimizing the impacts of volatile organic carbon compounds (especially from paint and carpet), wastewater, exterior light pollution, carbon dioxide, and non-recyclable operating materials. By incorporating the considerations in this manual that are affordable during building design and construction, field stations and marine laboratories will be providing examples of the attributes that we need all structures to incorporate to make our existence more sustainable.

Brian D. Kloeppel
OBFS President
Western Carolina University
November 2008

FORWARD

This publication is produced in the spirit of the noble cause of preserving the Earth's natural resources. The planet is our shared home and its natural resources represent our life support line.

By helping the scientific research community to achieve its goal of building environment-friendly research field stations and marine laboratories, we try to fulfill our ethical responsibility and obligation towards the planet.

Buildings alter their surroundings and sometimes they interfere with or disrupt the native ecosystems. However, with sensitive design and careful operation and management, buildings can perform in harmony with the environment or at least minimize their invasive impact to an absolute minimum. That is the goal and hope of this design manual.

Khaled Mansy & Gregory Gundersen
Oklahoma State University
December, 2008

A. A CALL FOR SUSTAINABLE FACILITIES FOR FIELD STATIONS

BIOLOGICAL FIELD STATIONS and marine laboratories represent the premier facilities in North America where the most pressing environmental challenges facing science and society can be directly confronted and understood through research and education. These challenges include, for example, maintenance of biodiversity, ecological sustainability, environmental forecasting, restoration and rehabilitation of damaged ecosystems, the outbreak and spread of diseases and invasive species. Not only do field stations provide broad geographic and thematic coverage, but they have also established strong partnerships with agencies and non-governmental organizations. Most field stations work with their nearby state and federal land management or wildlife organizations. Nearly all field stations collaborate with local citizen groups and many offer K-12 programs, thus providing direct linkage between research and public education.

There is an increasing imperative for biological field stations and marine laboratories to be long-term, stable operations that produce top-quality research without negatively affecting the environment. What follows are several reasons that sustainability will improve field stations, case studies to showcase the best of what can be done, and guidelines to help managers, architects, and institutions get started.

Infrastructure

Biological field stations and marine laboratories face a chronic problem of funding their operational costs. While grant money may be obtained for research or for the funding of equipment or building projects, the day-today operations of the facilities often lack a continuous financial support. As a result, the infrastructures of biological field stations and marine laboratories are often weak at best.

The irony of this situation is that the best research is usually long-term and focused upon a single system. For a field station to be successful at serving long-term research projects, uninterrupted operation of the facility is paramount. This means that having a wise monetary policy and a stable infrastructure are essential for good research.

Sustainability can be a key to helping field stations achieve financial security. Designing a new facility (or retrofitting an old one) to be sustainable does not always require extra initial costs, since energy saving measures are likely to pay for themselves. Sustainability is a sure investment, easily calculated by comparing initial costs with anticipated monthly savings. Indeed, the environmental sustainability of a biological field station leads to its economic sustainability. This is likely to be increasingly true with rising energy costs.

Recruitment

Recruiting successful scientists and students is essential to the production of quality research. A sustainable field station is attractive for several reasons. With a stable infrastructure, field stations can pass on savings to research, better equipment, outreach, building upkeep, and other needs that historically have lacked funding. By being able to consistently provide this support, field stations will be more attractive to scientists and students. Furthermore, sustainable design can provide more comfortable and natural spaces. Daylit laboratories, naturally-ventilated dorm rooms, comfortable space heating and cooling, green roofs with local plant life—these and other amenities that come with good design all encourage healthy living and embrace the local biota that is the focus of the field station's work.

Environment

Building facilities for a biological field station in a preserved habitat creates a unique contradiction of ideas. Research must take place in a natural environment where scientists can analyze flora and fauna without the influences of humans, but constructing a new building on a preserve will inevitably alter the habitat.

Therefore, understanding sustainable design and construction practices is crucial for field stations. Through proper planning, the location of the facility can minimally impact areas of research. Ease of access should also be considered, as getting supplies and vehicles on the site has undesirable environmental effects. Careful construction practices, such as properly removing waste, controlling run-off, and educating contractors on the importance of minimal impact can leave the site as untouched as possible by the end of the process. Finally, by wisely using the land, a biological field station can retain its most precious resource: the habitat being studied. Through all these means, field stations can remain consistent with the needs of the scientists.

Education

Many biological field stations and marine laboratories have educational programs for students of all ages, as well as for the general community. This relationship is an important link between the work that the researchers are doing and the community they intend to benefit. It is important for both scientists and students to be reminded of how the research is bettering the community and the world and to publicize the research beyond the scope of scientific journals.

Having a sustainable facility provides another important outlet for educating the public. With current concerns of humanity's impact on the biosphere, scientists help lead the way to a greener society. Humanity's greatest impact on the earth is the built environment; coming to an understanding of how to build sustainable facilities at field stations reinforces the work that environmental scientists do every day.

What makes a building sustainable?

Depending on the context of its use, the term sustainability has several definitions and meanings. However for the purpose of this design manual, the authors adopt pragmatic definitions of sustainability and sustainable architecture that are explained below. The popular UN-adopted definition of sustainable development reads: "development which meets the needs of the present without compromising the ability of future generations to meet their own needs". This definition addresses sustainability as an inter-generational issue. Indeed, when it is applied to specific disciplines, e.g., architecture or engineering, it needs further exploration of its meaning and attributes.

Buildings are end users of natural resources. During their construction, operation and demolition, buildings use substantial amounts of energy, water, and materials. True sustainable buildings should minimize the consumption of these natural resources. A 100% sustainable architectural development should be an integral part of its context, so it results in net zero consumption of energy, water, and materials. The success of sustainable design is measured based on how close the building is to being 100% sustainable.

Two definitions are adopted in this design manual; one is a definition of sustainability and the other is for sustainable architecture.

Sustainability is a design approach that maintains both a continuing development and a balance with the environment. Therefore, Sustainable Architecture can be defined as a new generation of buildings that performs more efficiently and does not harm the environment. In other words, sustainable buildings should be both Environment-Friendly and High-Performance buildings.

> *Sustainable Buildings should reduce the use of purchased energy in their operation. Building systems, e.g., heating, cooling, lighting, and the equipment and appliances inside the building consume energy to operate. Any reduction of this energy consumption makes the building more sustainable.*
>
> *Sustainable Buildings should reduce the use of water. In a typical building, drinking, bathing, washing, and flushing toilets consume potable water. Any reduction of the use of this water makes the building more sustainable.*
>
> *Sustainable Buildings should reduce the use of materials. Buildings use substantial amount of manufactured materials that may be transported by vehicles for hundreds or thousand of miles. These materials are used either used during the construction of the building or consumed in the daily operation. Any reduction of the consumption of materials makes the building more sustainable.*

Biological field stations and marine laboratories make a unique building type. They require facilities that are most likely to be located within a sensitive landscape, where scientists do research on ecosystems in natural environments away from urban areas. The unique use and location of biological field stations and marine laboratories call for their facilities to be designed, built, and operated in a sustainable manner in order to minimize or eliminate their environmental impact and to maintain the natural balance between local ecosystems. Furthermore, the remote location of biological field stations and marine laboratories necessitates, or favors, a development that is self-sufficient of its consumables, i.e., energy, water, and materials. Reducing the cost of maintaining a field station reduces the risk of building one, i.e., makes it more feasible to build new field stations. According to the Organization of Biological Field Stations (OBFS), "if you cannot maintain it, do not build it".

B. PURPOSE OF THIS PUBLICATION

THE PURPOSE OF THIS PUBLICATION is to assist research institutions in their pursuit to either build new facilities or to retrofit existing facilities of biological field stations and marine laboratories. Because it is likely that some or all attributes of sustainable facilities make functional and/or economic sense for biological field stations and marine laboratories, the authoring team of this manual decided to produce it in a form of comprehensive design guidelines, which if implemented, all or in part, should help both the research institution and the commissioned architect to design a truly sustainable facility.

C. THE INTEGRATED DESIGN PROCESS

DESIGN OF SUSTAINABLE BUILDINGS is only achievable through the implementation of the Integrated Design Process. Since the design of sustainable buildings must consider the optimization of their environmental performance and not only their aesthetics, special technical and quantifiable measures should be addressed during the architectural design process. Only the early study and integration of these measures into the design process guarantees a successful design of a sustainable (green) field station. This manual is intended as a comprehensive road map for the successful design of sustainable field stations.

Sustainable measures suggested in this design manual should be used by the research institution to assess and direct the in-progress design of a proposed facility. These measures (see section E1 Design Challenges) are intended to inform the client institution and enable its representatives to engage in a productive dialogue with the architect selected to design the sustainable facility. They also may be used as a checklist by the architect to review and to consider during the design of that facility.

D. FINANCIAL BARRIERS

HIGHER INITIAL COST of some of the sustainable measures should not deter the exploration of their application. Currently, some sustainable measures may not make financial sense for buildings located in proximity to municipal areas served by utility companies. In contrast, dependence on utility companies for remotely-located buildings may not make financial sense or may not be available at all.

Furthermore, with the rising cost of energy and water, and with sustainable technology becoming mainstream and less expensive, it is likely that over the total life of the facility sustainable measures can pay for themselves.

Sustainable field station facilities that cost almost the same as traditional ones can be seen in the case of Jasper Ridge Biological Preserve near Palo Alto, California; and the Center for Science and Education and the Forest Lodge at Black Rock Forest, New York. For more information on these two projects, refer to the case study buildings at the end of this manual (Section F).

E. INTRODUCTION TO THE DESIGN GUIDELINES

The proposed design guidelines are tailored to biological field stations and marine laboratories, and not general-use design guidelines that can be applied to any sustainable building regardless of its function. First, we identify the design factors that distinguish biological field stations and marine laboratories from other building types.

Special Nature of Field Stations and Marine Laboratories

Architectural design of facilities at biological field stations or marine laboratories should take into account their unique building type. Below is a list of features of a typical field station that influenced the development of the design guidelines proposed in this manual.

List of unique features:

1. Remote location, i.e., away from urban areas. This situation calls for self-sufficiency with less or no reliance on utility companies for supply of energy, water, and materials. Remote location also makes it much harder and/or more expensive to find skilled labor to maintain the facility.
2. Sensitive surrounding environments, i.e., these facilities are often located within a preserved natural landscape that should not be altered or destroyed.
3. Seasonal occupancy, i.e., a field station can be more frequently used in summer but is less occupied during the winter season.
4. Partial occupancy at any given time, with some parts vacant.
5. The critical need to reduce operating cost; continuing funding to maintain the facility is difficult to secure.
6. Primary use by ecologists. Ecologists respect the environment and tend to be knowledgeable about strategies to conserve natural resources.

In the rest of section E, the design guidelines are presented in six categories:

1. Design challenges: this category presents a number of architectural design issues that should be addressed during the design phase. Each design challenge is presented in the same format, i.e., design objective, potential solutions, design concerns, suggested design-assisting tools, and useful references.
2. Funding opportunities and incentives: suggests sources of funding or cost-savings to support the design of green buildings, biological field stations, and marine laboratories.
3. Architect selection: suggests how the research institution may select the ideal architect.
4. Performance-based contracts: suggests a specific format for the contractual agreement between the research institution and the selected architect.
5. Site work during construction: suggests precautions that should be implemented on the construction site to minimize disturbance to the surrounding environment.
6. Commissioning and quality control: suggests a means to verify the performance of the facility during the design and after construction.

We understand that not all recommendations may work for all field stations. It is up to the client institution and the architect to investigate the aptness of each recommendation as it applies to their project.

E1. DESIGN CHALLENGES

1. Programming

Design Objective

It is essential to keep the construction cost of the new facility as low as possible, so its initial cost is not prohibitive to building it. It is also important to design a facility that is appropriate for and desirable to the scientists.

Recommendations

For planning purposes of a biological field station facility, the client institution should have a clear vision of the expected uses of the facility. These uses should determine the program for the facility. The Organization of Biological Field Stations (OBFS) provides valuable suggestions on the planning for new facilities in its Operations Manual (section on: Facilities). In addition to the OBFS suggestions, this manual suggests the following design considerations for a sustainable and desirable field station.

Multi-use

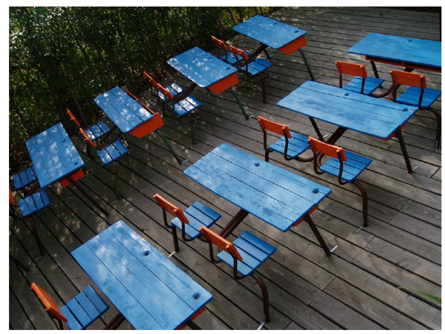
Because of the often partial occupancy of the different spaces in a field station, the inclusion of multi-use spaces makes financial sense.

A laboratory can be shared by different groups of non-resident scientists when proper scheduling is possible. In this case, each group may desire that their equipment be locked in a safe room while they are not present.

Small classrooms can be combined into a larger classroom or a larger lecture/seminar room. The same audio-visual equipment and chalk boards can be used for both small and large spaces. The daylighting systems should be designed to serve both large and small rooms.

Outdoor classrooms

In climates where outdoor conditions are within the thermal comfort range when the facility is in use, covered outdoor classrooms without climate control can be a desirable option to save energy.



OUTDOOR CLASSROOMS: A typical outdoor classroom that can also be used for eating and relaxing.

Sleeping facility

Not all scientists who use field stations stay for extended periods of time. Scientists usually stay for few days to collect and process samples. However, especially in the case of extended visits, scientists prefer to stay in detached cabins in close proximity to the research station. Sleeping wards for multiple occupants are not universally desirable, since they are less likely to encourage scientists to use the facility and/or stay overnight. Cabins of 400-700 square feet are suitable for extended stays. However, a disadvantage of detached cabins is that they are more exposed to the exterior climatic conditions, which should result in higher energy used for heating and cooling, especially in harsh climates.

SLEEPING FACILITIES: Individual cabins for extended periods of stay.

Storm shelters

For field stations located in areas with possible violent weather, e.g., tornados and hurricanes, it is always recommended that the facility includes a storm shelter properly-sized for the expected number of occupants. A good practice is to build the restrooms out of concrete walls with a concrete ceiling and FEMA-approved metal doors, and use them as a storm shelter. This way in the case of an emergency, occupants have access to water supply and restrooms. Doors of storm shelters should open to the inside, so they are not blocked with debris in case the building is hit and damaged by a storm.

Facilitating interdisciplinary interaction

One of the unique aspects of a field station is the close living proximity of very diverse scientists- geologists, forest pathologists, quantitative geneticists, botanists, physiologists, etc. Field stations foster discovery often by setting up conditions where these scientists with diverse backgrounds can interact. Shared facilities like dining halls or where regular meetings of the transient residents can occur have in many cases resulted in new discoveries.

For users who stay overnight or for extended periods of time, capacity for entertainment or leisure activities is desirable. Some field stations have a swimming pool [example: The Llano River Field Station Junction, TX, more information can be found on its website.], which is expensive to build, maintain, and insure; some other stations have tennis, volleyball and/or basketball courts, an outdoor pavilion, a gazebo with a barbeque grill, an outdoor semi-covered theatre, or a camping facility. A screened porch nearby or attached to the sleeping facility and overlooking the surrounding landscape is highly desirable for late afternoon gatherings and discussions. The screened porch is not air conditioned and its use should not consume energy.

Wildland Fire

The facilities should be designed and constructed with materials that will increase the chances that an un-occupied or lightly staffed facility will survive a wildland fire. In areas prone to wildfire, the FIREWISE program may need to be implemented in landscaping design.

2. Appropriate Site Selection & Planning

Design Objective

Early in the design process and often before the design begins, the site of the facility is selected. Site selection should not dictate any restrictions on the design and should provide greater opportunities for how sustainable the facility can be. Keep in mind throughout the following recommendations that any construction in a sensitive location will inevitably have some environmental impact due to accessing and preparing the site.

Recommendations

Build on a relatively high elevation

Where possible, select a site on a relatively high elevation. The high elevation provides the following advantages:

- Better views of the surrounding landscape.
- Less probability of flooding due to heavy rain.
- When high elevation is coupled with the site being away from tall trees or any similar obstructions, the following advantages are possible:
    1. More effective passive cooling through natural ventilation or the stack effect due to higher wind velocity. Passive cooling systems reduce the dependence on mechanical cooling, only when outdoor temperature is favorable.
    2. Higher potential for power generation by wind turbines due to higher wind velocity.
    3. Higher potential for power generation with the use of south-facing PV (Photo-Voltaic) panels.
    4. Higher potential for passive solar heating systems that reduce

heating loads. Passive solar heating may be designed to replace or reduce the need for mechanical heating.

[Note: A lightning rod should be properly installed and grounded when the facility is built on a high elevation in an area where thunderstorms are common.]

[Note: To minimize the probability of wind damage during storms, it is preferable that the facility is not built on the highest location.]

Build away from tall trees and dry grass

To protect the building from potential safety hazards, the site should be selected to be away from tall trees and dry grass.

- Old tall trees may fall due to high winds. They also reduce natural light, solar heating and photovoltaic potential. For existing buildings, close by trees should be cut down or at least regularly trimmed. Close by dead trees should be cut down.
- Dry grass facilitates the spread of fire and should be separated from structures by a reasonable buffer zone. For the same reason, deciduous vines growing on buildings are not recommended.

Build on a south-facing site (northern hemisphere)

A south-facing site that enables building a south-facing facility that is elongated on the east-west axis will provide three opportunities:

- Passive solar heating for the building's occupied spaces (in colder climates).
- Passive solar water heating that may replace or reduce the need for electric or gas-fired water heaters.
- Plenty of natural light, reducing the need for artificial lighting.

Build on a flat site

In case the site has a highly permeable soil, build the facility on a relatively flat site. Flat sites eliminate the possibility of the soil being washed away from underneath the building in case of highly permeable ground. If a flat site is not available, a perimeter footing drain is necessary, which may increase construction cost.

Minimize site disturbance

In order to maintain the natural balance in the site, it is important that the planned facility does not disturb the surrounding landscape. The recommendations below are suggested by LEED in its section on sustainable sites.

- Selected site should preserve existing habitat, natural resources, and biodiversity, except for trees, grasses and associated wildlife removed during site preparation.
- Maintain natural stormwater flows by promoting infiltration. The facility may have vegetated roofs and pervious paving, and reuse stormwater for non-potable uses.

MINIMIZE SITE DISTURBANCE: A green roof helps blend a building into the surroundings.

3. Efficient Envelope Design

Design Objective

The environmental performance of a building depends essentially on the design of its shell. This shell is also known as the envelope or the skin.

Buildings built within city limits must comply with building codes enforced in the jurisdiction, including requirements of thermal insulation and a vapor barrier within the envelope. Although field stations are usually located outside city limits, at minimum they need to comply with current local building codes in order to avoid wasting energy.

SUPER INSULATION: Installation of more insulation than what is required by code.

Recommendations

Comply with building codes, at minimum

A field station should comply with the recommended building codes for its climatic region. Currently, the International Energy Conservation Code (IECC 2006) is the applicable and most-adopted code in the United States, which recommends the minimum values of thermal insulation. Minimum values of insulation reduce energy waste, but do not guarantee that the building is maximally energy efficient.

Super insulation

High performance buildings often have more insulation than what is required by code. Insulation is relatively inexpensive and does not add much to the construction cost.

Cost-effective thickness of insulation should be determined based on a life cycle cost analysis to optimize the financial benefit of additional insulation. In general, adding insulation past the point of diminishing return is fiscally ill-advised.

Avoid exposure to east or west

In climates where cooling load is dominant, the massing and envelope design of the field station should avoid exposure to east and west as much as possible. Solar heat gains received from east and west are usually much higher than north or south.

AVOID LARGE WINDOWS: Windows should be properly insulated.

Avoid large windows

Especially in harsh climates, the design of the building envelope should avoid large windows as much as possible. Typically, glass (including insulating glass) has a much lower thermal resistance to the flow of heat from the outside to the inside and vice versa, which results in much higher cooling load in summer and much higher heating load in winter. Furthermore, large windows also increase thermal loads due to possible air infiltration and/or exfiltration. Windows should be sized appropriately to minimize heat loss and heat gain.

Instead of minimizing the area of glass, large high performance windows can be used. However, the use of high performance windows is usually a more expensive solution and adds to the construction cost of the building. However, this can be justified based on a life cycle cost analysis.

4. Energy Efficiency / Cooling Load Reduction

Design Objective

Energy efficient buildings consume less energy than similar-use buildings in similar climates. A building is energy efficient when its building systems consume less energy to operate as a result of reduced systems' loads. Load reduction is crucial for the design of low-energy (sustainable) buildings.

When the cooling load of buildings is reduced, the size of the HVAC system can be reduced which results in an immediate reduction in the construction cost. Furthermore, this is also associated with a reduction in the operating cost of the facility, which is another crucial benefit for a self-sustaining field station, especially if built in a remote area.

Cooling loads can be reduced when one or more of its four load components is reduced, i.e., solar load, transmitted load, internal heat gain, and outside air load. Also, the need for mechanical cooling can be reduced if natural ventilation is possible during the cooling season.

[Note: In certain types of laboratories natural ventilation is not desirable because open windows may also admit noise, dust and humidity. Humidity harms the performance of computers and sensitive electronic equipment typically in use at scientific facilities.]

Recommendations

Reduce solar loads

Solar radiation through windows adds significant cooling load to spaces exposed to direct sunlight and to large areas of bright sky. Solar radiation can be reduced when following some or all of the following recommendations:

- Reduce areas of glass, especially glass facing east and west. The sun is low in the sky on the east and west, which results in relatively high solar intensity on vertical glass facing east and west.
- Protect glass against direct sunlight with properly-sized overhangs and/or vertical fins. Overhangs can protect windows facing south, east, and west. Vertical fins can protect windows facing east and west. [Note: the overhang is an external shading device that is attached to the exterior wall above the window.]
- Select a glass type with low Shading Coefficient (SC) and Solar Heat Gain Coefficient (SHGC) values. For the maximum SHGC value

REDUCE SOLAR LOADS: Louvers protect the glass against direct sunlight.

for glass in a certain climatic region, the architect should refer to the current IECC (International Energy Conservation Code).

- At times when the glass is un-shaded, use internal shading devices, e.g., Venetian blinds, to stop the solar radiation at the window.
  [Note: In this section of the recommendations, the facility is assumed to be located in the Northern Hemisphere. If the facility is located in the Southern Hemisphere, north-facing glass will receive the solar radiation, and not the south-facing glass.]

Reduce transmitted loads

Heat flows naturally from the higher to the lower temperature across the building envelope. It is a process that continuously adds heats to interior spaces during the hot season and removes heat from the interior during the cold season. Reduction of this heat gain can be achieved by applying the following recommendations:

- Avoid large windows since glass has a much higher thermal conductance than opaque walls.
- Use a glass type with the lowest thermal conductance (U value) as possible. For the maximum U value for glass in a certain climatic region, the architect should refer to the current IECC (International Energy Conservation Code). [Note: be aware that the IECC lists U values in IP units, i.e., Btuh/sq ft.o F, and some European glass manufacturers provide the U-value in SI units, i.e., Watt/sq m.o K].
- Use thermal insulation within the envelope. For more information, refer to the section titled “super insulation” in design challenge # 3 (Energy Efficient Envelope).
- Use high thermal mass walls that can delay heat transfer across the envelope.
- Shade exterior walls from direct sunlight as possible. Shading exterior walls reduce the sol-air temperature, which is the temperature of the outside surface of the envelope due to the combined effect of outdoor temperature and direct sunlight. Exterior walls can be shaded by overhangs, louvers, or porches

Reduce internal heat gains

Heat build up in the interior spaces adds to the cooling loads that must be removed by the building’s HVAC system. Internal heat gains can be reduced by following these recommendations:

- Use energy-efficient equipment and appliances. Due to the laws of thermodynamics (conservation of energy), electricity consumed by electric equipment and appliances inside the building generate heat that contributes to the space cooling load. Use of energy-efficient devices, e.g., Energy-Star labeled appliances, will greatly reduce the cooling load.
- Use an energy-efficient electric lighting system. Similar to the energy efficient devices, energy-efficient lighting systems prevent the unnecessary increase in the cooling load.

- Turn off non-essential lighting, equipment and electronics when not in use. This can be done manually or with the help of an automated control system.

Reduce outdoor air loads

Occupants need certain amounts of fresh outside air for ventilation. In summer, ventilation air brings heat gain with it to interior spaces. Air infiltration through cracks in the building envelope is another source of heat gain. This air change (through ventilation and infiltration) is also required to protect public health from materials' off-gassing and possible cross contamination in laboratory buildings. In order to reduce cooling load due to continuous air change, the following recommendations may be followed:

- Use the economizer cycle. This cycle is explained in detail in design challenge # 6 (Efficient HVAC Design / systems selection & operation).
- Use the appropriate type of heat recovery systems. These systems are explained in detail in design challenge # 6 (Efficient HVAC Design / systems selection & operation).
- Use double doors for frequently used exterior doors.

Night Purge

Night purge is an operation that is utilized to pre-cool the thermal mass of a building during night hours in the cooling season. When the thermal mass is pre-cooled, cooling loads the next morning are lowered, which results in less energy consumed by the HVAC system. Thermal mass is cooled by allowing cooler night air to penetrate hollow structural systems or hollow flooring systems, but not interior spaces through windows. Windows of buildings cannot be left open at night when the building is unoccupied for security and safety reasons.

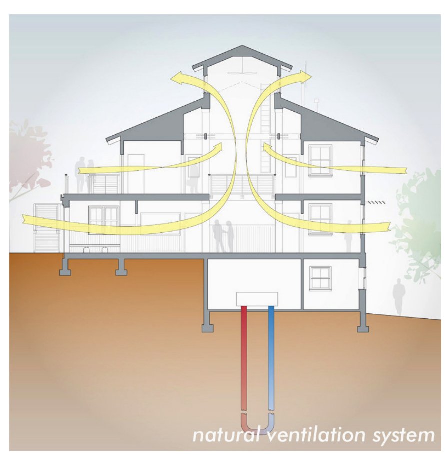
Evaporative cooling

Evaporative cooling is a low-energy strategy in which mechanical cooling is provided by means of water evaporation. Swamp coolers can utilize water evaporation to cool outside air in dry climates. However, evaporative cooling is not as effective in mixed or humid climates. To avoid depleting water resources, stormwater and/or gray water should be used whenever feasible.

Natural ventilation

Reliance on mechanical cooling can be reduced when natural ventilation is possible during the cooling season. In general, natural ventilation is only possible if outdoor temperatures are below 75 – 80 ^{o}F. When natural ventilation is in operation, mechanical cooling equipment should be shut down in order to save energy. It should be noted that because natural ventilation happens through open windows and mechanical cooling required closed windows, integration between natural ventilation and mechanical cooling is not possible. Natural ventilation systems may include:

NATURAL VENTILATION: Stack effect ventilation system. Drawing courtesy of FXFOWLE ARCHITECTS, PC.



NATURAL VENTILATION: Stack effect ventilation through an atrium roof.

- Cross ventilation systems, in which a natural flow of colder air is allowed to pass through the interior spaces in order to flush the internal heat gain to the outside. The effectiveness of this process is proportional to the varying wind speeds.
- Stack effect ventilation systems, in which the system can operate in calm wind conditions. With the help of a tall stack, hot air exiting the stack by buoyancy draws colder air into the interior spaces, ultimately flushing the internal heat gain to the outside.

Power ventilation

Power ventilation is a low-energy system in which only an electric fan is used to continuously change the air inside the building when outdoor conditions are prevalent for natural ventilation even in calm wind conditions. When power ventilation is in operation, mechanical cooling equipment should be shut down in order to save energy.

5. Energy Efficiency / Heating Load Reduction

Design Objective

In buildings, when the heating load is reduced, the size of the boiler or the furnace can be reduced which results in an immediate reduction in the construction cost. Furthermore, this is also associated with a reduction in the operating cost of the facility, which is another crucial benefit for a self-sustaining field station, especially if built in a remote area.

Heating loads can be reduced when one or more of its two load components is reduced, i.e., transmitted load and outside air load. In climates where passive solar heating is possible, mechanical and/or electrical heating equipment can be reduced or eliminated.

Recommendations

Reduce transmitted loads

Because nature always seeks balance, heat flows naturally from the higher to the lower temperature across the building envelope. Buildings during the cold season lose heat to the outdoor. Reduction of this heat loss can be achieved by applying these recommendations:

- Unless facing south, avoid large windows, because glass has a much higher thermal conductance than opaque walls.
- Use a glass type with the lowest thermal conductance (U value) as possible. For the maximum U value for glass in a certain climatic region, the architect should refer to the current IECC (International Energy Conservation Code).
  [Note:] Be aware that the IECC lists U values in IP units, i.e., Btuh/sq ft.o F, and some European glass manufacturers provide the U-value in SI units only, i.e., Watt/sq m.o K]

[Note:] To obtain Btuh/sq ft.o F, divide Watt/sq m.o K by (5.678)

- Use thermal insulation within the envelope. For more information, refer to the section titled "super insulation" in design challenge # 3 (Energy Efficient Envelope).
- Use high thermal mass walls that can delay heat transfer across the envelope.

Reduce outdoor air loads

Occupants need certain amounts of fresh outside air for ventilation. In winter, ventilation air increases heat loss from interior spaces. Air infiltration through cracks in the building envelope is another source of heat loss. This air change (through ventilation and infiltration) is also required to protect public health from materials' off-gassing and possible cross contamination in laboratory buildings. In order to reduce heating load due to continuous air change, follow these recommendations:

- Use the economizer cycle. This cycle is explained in detail in design challenge # 6 (Efficient HVAC Design / systems selection & operation).
- Use the appropriate type of heat recovery systems. These systems are explained in detail in design challenge # 6 (Efficient HVAC Design / systems selection & operation).
- Use double doors for frequently used exterior doors.

Passive solar heating

Whenever climatic conditions are favorable, the facility may rely on solar heating to reduce or eliminate the need for mechanical and/or electrical heating. Passive solar heating is possible in cold climates under clear sky or partly cloudy sky conditions. In these conditions, windows should be positioned and sized properly in order to harvest sufficient solar radiation. Properly sized south-facing windows with the right glass type can harvest more solar heat than the heat they lose to the outside, which results in a net heat gain. If this heat gain is enough to substantially heat the building, heating equipment can be shut down or used less. [Note: architects must seek the assistance of an expert of building science to properly size the south-facing windows for passive heating.] A complete design of a passive heating system includes three components, which are:

PASSIVE SOLAR HEATING: Natural daylight provides light and warmth.

- South-facing windows to harvest solar radiation.
- Indoor thermal mass to store the heat and then release it when needed.
- Night movable insulation on windows from inside to minimize heat losses during nighttime. Night insulation can be controlled either manually or by an automated system.

PASSIVE SOLAR HEATING SYSTEMS: Water-filled pipes are heated by the sun, providing hot water for the residence.

Passive solar heating systems are designed to harvest solar radiation during daytime and store the heat in the building's thermal mass till nighttime when the heat can be released to the occupied spaces. In general, two types of passive solar heating systems can be identified:

- Direct heat gain systems, in which the heat is collected and stored in the thermal mass of the occupied space itself. In these systems, temperature cannot be fully controlled and occupants may experience a noticeable swing of temperature between day and night.

- Indirect heat gain systems, in which the heat is stored in the thermal mass of an auxiliary space, then transferred or circulated to the occupied spaces only when needed. Examples of these systems include: solariums, Trombe walls, roof ponds, and rooftop solar collectors.
- [Note: In this section of the recommendations, the facility is assumed to be located in the Northern Hemisphere. If the facility is located in the Southern Hemisphere, north-facing glass will receive the solar radiation.]

6. Efficient HVAC Design/Systems Selection & Operation

Design Objective

Selection of the appropriate HVAC system is of paramount importance. HVAC systems differ in their initial cost, how they respond to thermal loads, efficiency and operating cost, and environmental impact. Selection of systems that can respond to the often partial occupancy of field stations and their remote location is advised. Selection of heating and cooling equipment with efficient part-load performance characteristics can significantly lower operational cost. The section below provides a detailed list of recommendations.

Recommendations

Fuel type

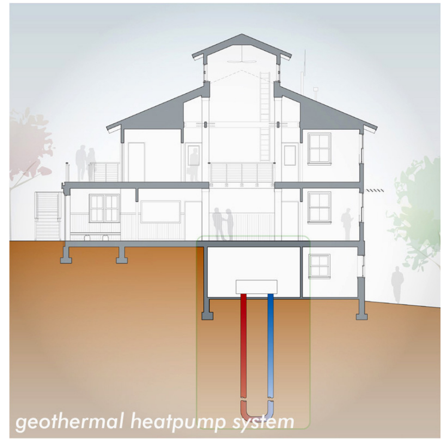
The most sustainable source of energy for a biological field station is a renewable non-polluting source. Where that is not possible, the source of fuel used to run the building's mechanical and electrical equipment should be:

- Locally or regionally available. Depending on the regional market, fuels available can be: coal, oil, natural gas, propane, or electricity.
- Clean energy source. Electricity is a non-polluting form of energy; however it is a carrier of energy that is usually generated somewhere else where pollution occurs if the power plant burns a fossil fuel. Natural gas is the cleanest fossil fuel to burn on site, when compared to oil and coal. Coal is the most polluting.
- Ease of storage. In case of remote locations, storage of fuel can be challenging. As example, oil storage may cause spills that harm the sensitive surrounding landscape.
- Biofuels, where locally available, should be considered.
- For field stations built in wooded biomes, harvested wood can be utilized as a source of heating. Wood can be burned in fireplaces or as a fuel for a central heating system.

Central sources of heating

Besides the traditional use of gas-fired boilers and furnaces as a central source of heating, other options may include:

- Solar energy, which can be used to heat water and then distribute this water to deliver heating to interior spaces. Effectiveness of solar heating systems depends on the % cloud cover in the location. If solar heating is utilized, also install a supplementary active system, e.g., a gas furnace.
- Incinerators, which recover energy from solid waste. Where quantities of solid waste on site are large, incinerators may be cost effective. Modern heat recovery incinerators convert the refuse into carbon dioxide and water vapor, flue gas, and ash, and permits the system to meet the EPA (the US Environmental Protection Agency) emissions standards. However, it is still recommended to locate the incinerator away from the facility.
- Ground source or water source heat pumps. These systems use the soil as a heat sink to provide heating and cooling to buildings. Heat pumps consume electricity to run, and are usually very efficient with very high COP (Coefficient Of Performance).
- Geothermal wells if available in the region.



GROUND SOURCE HEAT PUMP: Uses the thermal stability of the earth to heat and cool a building. Courtesy of FXFOWLE ARCHITECTS, PC.

Central sources of cooling

Besides the traditional use of the refrigeration cycle as a central source of cooling, other options may include:

- Ground source or water source heat pumps. These systems use the soil as a heat sink to provide heating and cooling to buildings. Heat pumps consume electricity to run, and are usually very efficient with very high COP (Coefficient Of Performance).
- Nearby lake or river if available. Large bodies of water may be used as a source of free cooling when coils are run into the deep water that stays cold during summer months. If deep water is not cold enough, heat pumps can be used. The result is a very efficient cooling system. It should first be ascertained that there will be minimal negative environmental impacts on lake/river biota due to localized heat load.

The economizer cycle

To minimize energy consumed in heating and cooling, the use of the economizer cycle is highly recommended. In the economizer cycle, the air handler mixes the return air with outdoor air in order to minimize the amount of outdoor air but keeps it above what is required to maintain the indoor air quality. Fresh outdoor air is hot in the cooling season and cold in the heating season. Introducing less fresh air increases the efficiency of HVAC systems.

It should be noted that return air from laboratories that may cause cross contamination or lower air quality should be exhausted directly to the outside and should not be allowed to return back to the air handling unit, i.e., cannot be re-circulated using the economizer cycle.

Heat recovery

Ability to recover heating or cooling from the exhaust air increases the efficiency of HVAC systems. Heat recovery units can be as simple as the plate-to-plate type and as complex as the energy recovery wheels.

- Plate-to-plate heat recovery units allow heat exchange between the fresh and exhaust air without mixing the two streams of air, which eliminates the possibility of cross contamination and low air quality. These units are efficient, inexpensive, and do not require frequent maintenance.
- Heat recovery wheels can exchange heat and humidity between the fresh and exhaust air without mixing the two streams; however they add significant pressure to the system, and require a motor to spin the wheel. These units are expensive and require frequent maintenance and spare parts.

Systems for partial occupancy

Because some spaces in the biological field stations and marine laboratories can be occupied while others are not, the selected HVAC system for the facility should be able to respond to partial occupancy, i.e., partial load of heating and cooling.

- Avoid single-duct single-zone systems, since these systems are designed to supply heating or cooling to a single thermal zone, with single occupancy. However, these systems can work well for individual cabins.
- Systems with terminal devices that can be individually controlled (manually and/or automated) suit partial occupancy the best. For example, the use of heat pumps in every thermal zone allows the maximum energy savings since only heat pumps in occupied spaces will operate while heat pumps in the rest of the facility do not. These systems will minimize energy that may be wasted in air conditioning unoccupied spaces.
- Variable speed drives for fans and pumps. Variable speed drives adjust the speed of motors to only meet the demand, i.e., adjust the speed of water loop pumps in response to demand for heating or cooling, and adjust the speed of fans in response to air pressure in supply ducts. Variable speed drives save energy and are reliable and cost effective.

Automated control

In order to reduce the use of energy, it is always recommended to use a type of automated control of the HVAC system in order to minimize energy consumed in air conditioning unoccupied spaces and to monitor the control of occupied spaces. These systems can be:

- An energy management system that is fully-automated and controlled only by the building engineer or the facility manager.

- Infrared or ultrasound occupancy sensors, with time delay.
- Time switches, for spaces with regular occupancy schedules.
- Day/night different setpoint temperatures, i.e. cooler at night due to varying density of occupancy.

Location of outdoor equipment

When outdoor equipment is used, noise can be an issue. Outdoor heat rejection equipment should be protected for better maintenance and higher efficiency. Detailed recommendations are below.

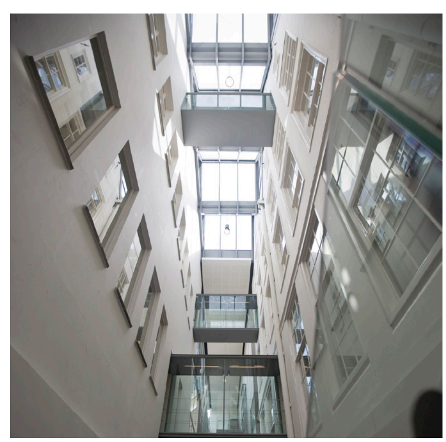
- Noisy outdoor equipment should be located away from sound-sensitive interior spaces and/or shielded by sound barriers.
- Heat rejection equipment, e.g., air-cooled chillers or condensers, should be protected from dust, falling leaves, and other organic debris. Dust and leaves block airways inside the heat exchanger (corrugated sheets and tubing), preventing proper air circulation, which significantly reduces the equipment's efficiency and/or increases the need and cost of maintenance.
- Locate heat rejection equipment to be shaded from afternoon sun during the cooling season.

For equipment selection, it is always recommended to specify HVAC equipment that does not use Hydrochlorofluorocarbon (HCFC) refrigerants (example: HCFC-22, also known as R-22). Leaked HCFC refrigerants contribute to stratospheric ozone depletion.
[Note:] In the US, HCFC refrigerants are scheduled for 100% phase-out by the year 2020.

7. Energy Efficiency / Daylighting

Design Objective

Natural light is a free renewable form of energy that can be utilized in buildings. Daylighting systems (windows and skylights) can provide enough illumination necessary to perform visual tasks inside interior spaces during daytime. Properly designed daylighting systems can reduce or eliminate dependence on electric lighting systems, consequently saving energy. Furthermore, daylighting systems maintain the relationship between indoors and the outdoors, which enhances both visual comfort and productivity of the occupants.



DAYLIGHTING: An atrium is daylit, requiring no electric lighting during the daytime.

Successful design of daylighting systems should respond to local climatic conditions and to the visual task performed in every space in the research facility. While daylighting systems may not be critical in sleeping quarters, it is of paramount importance in classrooms, offices, libraries, and some laboratories. A careful design of daylighting systems in spaces occupied during daylight hours is strongly recommended. Properly designed daylighting systems should also prevent penetration of direct sunlight into the space in order to avoid glare and visual discomfort.

Recommendations

North and south exposure

The north sky is the best source of uniform non-glare daylight . Year round, the sun reaches south, east and west-facing spaces. At high latitudes in summer, the sun can reach the north side of the building during early morning and late afternoon hours (Northern Hemisphere). When daylight is desirable for a non-residential space:

- Locate the space facing the north sky in order to prevent glare. Depending on an in-depth study, vertical fins may be required to protect north-facing windows against early morning and late afternoon sun during summertime.
- Locate the space facing south only if the windows are effectively shaded by overhangs. Facing south, the sun is relatively high in the sky and a properly-designed overhang can protect the glass against direct sunlight in summer.
- Avoid facing east and/or west, since the east and west sun is relatively low in the sky and overhangs cannot effectively shade the glass.

NORTH AND SOUTH EXPOSURE: South facing glass receives more daylight in the Northern Hemisphere.

Size aperture properly

Sizing windows and skylights for daylight should avoid down-sizing or over-sizing glass area. Although aperture is the source of light into an interior space, bigger is not always better. Larger-than-necessary glass area results in unnecessary high cooling load in summer and high heating load in winter. IESNA (Illuminating Engineering Society of North America) does not define a certain outdoor design condition to govern the design of daylighting systems, i.e., to be followed in sizing aperture. However when LEED certification is sought for the facility, architects should follow the recommended design condition suggested by the USGBC (US Green Building Council) in the LEED-NC (Leadership in Energy and Environmental Design-New Construction) rating system, which is:

- Design aperture to achieve a minimum illumination level of 25 foot-candles on the workplane under clear sky conditions, at solar noon, on the equinox (March 21st and September 21st.)

As an alternate to sizing windows according to LEED criteria, architects may elect to consider the overcast sky condition, at solar noon, on the equinox, since outdoor illumination levels under overcast sky are always lower than under the clear sky conditions.

Illumination level

The target daylight illumination level in interior spaces in the facility should follow the recommended illumination levels defined by the IESNA for the same (or similar) visual task performed in the space.

The use of light shelves with windows

Typically, windows provide much higher light intensity near the exterior wall compared to the light intensity deep in the space. This non-uniform distribution of light intensities in the space is undesirable. To reach a more even distribution of light in the space, the use of light shelves is recommended. A Light shelf is a horizontal reflector that is attached to the window in order to reflect the light towards the ceiling and the back of the space. Light shelves must be installed at a lower height than the top of the window, and can be located inside or outside of the window.

LIGHT SHELVES: Reflects the light from the window into the back of the room. Photo credit: Kawneer NA.

- When the light-shelf is installed inside the window, it can reflect the light farther back in the space, is easier to maintain, and is less expensive.
- When the light-shelf is installed outside of the window, it can better protect the interior near the window against the large area of bright sky, but it is hard to maintain, should be climate-resistant, and is more expensive.
- The light-shelf can be also partly inside and partly outside.

Room design

Because windows on one side of the room cannot provide high illumination levels towards the back of the room, it is recommended that daylit spaces be shallow. Architects may use common rules of thumb to predict the penetration depth of light due to the height of windows. [Note: The common rule of thumb is the 2.5 rule, which assumes a horizontal penetration depth of daylight equals to 250% of the height of windows as measured above the workplane.]

Control systems

Daylighting systems are designed to provide a certain illumination level inside the space under certain design conditions, i.e., a sky condition at a given time. Indeed, over a course of one year of operation, outdoor illuminance exceeds those of the design condition, which may result in higher illumination levels than what is desired associated with higher cooling loads in summertime. Ideally, windows and skylights should have means to reduce light penetration when necessary. These control systems can be one of the following:

- Manually adjustable Venetian blinds.
- Manually adjustable rolling shades.
- Automated rolling shades (or similar) controlled by a photoelectric sensor.

Glass type

Glass is not a 100% transparent material. The amount of light admitted through a window is determined by the glass visible transmittance. In order to reduce the area of glass (to make the facility more energy-efficient), it is recommended to choose a glass type with high visible transmittance.

When daylight is introduced through a flat skylight to a space where visual tasks are performed, it is recommended to use a translucent glass type for the skylight. Translucent glass prevents the penetration of direct sunlight into the building, which helps prevent glare. Another concern with flat skylights in extreme climates is the possibility of damage due to hail. Thus, it is recommended to use translucent Plexiglas, or tempered glass instead of translucent regular glass for skylights where hailstorms are possible.

8. Energy Efficiency / Electric Lighting Design

Design Objective

Daylighting systems may be designed to eliminate the need for electric lighting systems during daytime. However, during the times when daylight is unavailable (nighttime) and during overcast days (especially in winter) there is still a need for electric lighting systems.
Electric lighting systems often have low overall efficiency, but with careful design this efficiency can be maximized. The following recommendations are helpful to increase the efficiency of electric lighting systems. Efficient lighting systems consume less electricity and generate less heat gain, which subsequently reduces the cooling load carried by the HVAC system.

Recommendations

Use high efficacy lamp types

Artificial light sources (lamps) vary in efficacy. Efficacy is the ability of an artificial light source to convert the kinetic energy of a flow of electrons (electricity) into visible electromagnetic waves (light). Technically, efficacy of a light source is its luminous efficiency expressed by lumen output of lamps per power input in watts. The electrical engineer should try to use lamps of the highest possible efficacy as measured in Lumens per Watt (lm/W). For indoor use, it is recommended to:

HIGH EFFICACY LAMPS: New light bulbs are more efficient than ever before.

- Use full size fluorescent tubes, since these lamps have the highest efficacy.
- If the use of full size fluorescent tubes is not possible, use compact fluorescent bulbs.
- Avoid using incandescent light bulbs, which have the lowest efficacy.
- Although they are highly efficient, avoid using high intensity discharge (HID) lamps inside the facility, since they typically emit low quality light that may distort the perception of colors.

Use high efficiency light fixtures

Light fixtures also vary in efficiency. Efficiency of a light fixture is its luminous efficiency expressed as ratio of lumen output of fixture to lumen output of lamps inside the fixture. Due to the design of the light fixture, it only projects a percentage of the light emitted inside it. The remaining amount of light is instantaneously absorbed inside the fixture in a form of heat. High efficiency fixtures save energy. The efficiency of luminaires (%) is usually provided by the manufacturer. However, when selecting a light fixture, the recommendations below can be helpful.

- Select light fixtures that direct the light towards the workplane directly. Indirect light fixtures are typically of lower efficiency than direct ones.
- Select pendent light fixtures that do not trap the light inside. Some surface-mounted and recessed light fixtures trap a significant percentage of light inside.
- If surface-mounted or recessed light fixtures are preferable, select fixtures with highly reflective coating that effectively reflect the light out of the fixture.

Paint walls and ceilings light colors

Light-colored interior surfaces absorb less light and help reflect the light back towards the space itself. Architects may avoid matt dark-colored finishing materials.

Regular maintenance

Good maintenance of spaces and lighting systems help maintain efficiency.

- Keeping the walls and ceiling clean help maintain their reflectance.
- Cleaning and on-time re-lamping of light fixtures maintain the system's efficiency.

Outdoor lighting

For safety and security reasons, outdoor lighting is often necessary. Outdoor lighting should be designed to minimize light pollution also increases the system's energy efficiency. For this purpose:

- Direct light towards the building and only where it is necessary, but not towards the sky or surrounding landscape.
- Use narrow-angle spotlights and/or full cutoff luminaires that do not spill light into unwanted areas.
- Use low reflectance surfaces around the facility.

Automated control

To reduce the use of energy, use a type of automated control of the electric lighting systems in order to minimize energy consumed in lighting unoccupied spaces and to dim lights in daylit spaces. These control systems can be:

- An energy management system that is fully-automated and controlled only by the building engineer or the facility manager.
- Infrared or ultrasound occupancy sensors, with time delay. These are to be installed in small spaces, such as sleeping rooms, classrooms,

and restrooms.
- Time switches, for spaces with regular occupancy schedules.
- Photo-electric sensors in spaces that enjoy access to daylight.

9. On-Site Power Generation

Design Objective

In case the biological field station is located in a remote area where utility-supplied power is unavailable, too unreliable or too expensive, on-site power generation is desirable. On-site power generation can utilize renewable energy sources or fossil fuels. If the facility is designed to be sustainable in order to minimize its environmental impact, renewable energy sources should be utilized. When clean renewable energy sources are available and can make the building self-sufficient, this will surely maintain site balance and won't pollute the surrounding landscape.
Furthermore, renewable energy sources are free. Once the capital investment is spent to build a renewable energy generation system, power is essentially free, with low maintenance cost.

Recommendations

Photovoltaic solar panels

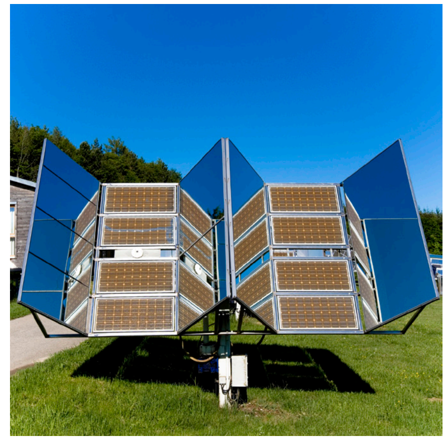
Photovoltaic panels generate DC (Direct Current) electricity, and operate in a circuit similar to a battery. Because most appliances and electrical devices run on AC power, an inverter is necessary to convert DC power to AC (Alternating Current) power. In order to utilize the crystalline silicon PV (Photo-Voltaic) systems to their maximum potential, the following recommendations may be followed.

PHOTOVOLTAIC PANELS: Integrated into the design of the house.

- When placing PV panels, avoid any obstruction of direct sunlight year round. PV panels generate far more electricity when exposed to direct sunlight than if placed in the shade or under overcast sky conditions.
- Annual energy generation by fixed-tilt PV panels is at its maximum when the tilt angle (measured from the horizontal) is equal to the latitude of the location, or about 3 degrees lower. When the tilt angle is equal to the latitude, the solar radiation is normal to the panel on solar noon during the equinoxes, which is the midpoint of the solar year.
- In order to maximize the amount of electricity generated by PV panels, concentrating devices or reflectors can be used to concentrate direct sunlight on the PV cells. The generation efficiency of PV cells stays the same, but with higher incident energy, the output is also higher.
- Sun-tracking PV panels can be one-axis tracking or two-axis tracking. One-axis tracking panels track the daily movement of the sun in the sky from east to west but its axis of rotation is fixed at the optimum angle and is oriented towards the south (in the Northern Hemisphere). Two-axis tracking panels move around vertical and horizontal axis and can track the sun the entire day year round. These sun-tracking

systems consume energy in continuously moving the panel, which reduces the net amount of energy they generate. A detailed study should be performed to ensure the cost effectiveness of these tracking systems compared to the fixed-tilt PV systems.

- When PV panels are mounted on roofs, they must be back-ventilated by outdoor air in order to cool them down. The actual voltage of a solar cell is dependent upon the ambient temperature; its efficiency drops with higher temperatures, and increases with lower temperatures.
- In climates where severe storms are possible, hail may break glazed panels. Cover the glass PV panels during storms or select Plexiglas panels if available.



PHOTOVOLTAIC PANELS: Oriented and designed for maximum solar exposure.

Instead of using the crystalline silicon PV panels, the flexible thin-film solar cell shingles can be used. Solar shingles are lightweight, easy to handle, and can be placed directly on a fire-resistant roofing underlayment. Back ventilation for solar shingles is not necessary. Solar shingles are much less expensive than the crystalline silicon PV panels; however they are also much less efficient. The best advantage of solar shingles is that they are structurally and aesthetically integrated with the architecture of the facility.

Wind turbines

Wind turbines (or wind mills) convert wind power to electricity. In areas with average local wind speed of 10 mph or higher, the use of wind turbines can be cost effective. The power contained within the wind is proportional to its speed cubed. If wind turbines are to be used for on-site power generation, consider the following:

WIND TURBINES: Smaller wind turbines can be less conspicuous while still generating power.

- The wind turbine should be located in an area that is not affected by nearby wind breakers that would interfere with free wind patterns.
- The wind mill should be installed so the propeller is at the highest height possible. Wind speed increases significantly with height above the ground, till a point of steady speed.
- Bigger is better with respect to energy: the energy generated by a propeller is proportional to its diameter squared.
- The structure supporting the wind turbine should be as open as possible, while still having the structural strength to withstand the wind load.
- Maintenance of small size turbines happen on the ground. The tower supporting the turbine is designed to be tilted 90 degrees to allow lowering the turbine to the ground level. Allow a sufficient free area to tilt the full length of the tower.
- Multivaned windmills are good for pumping, while a two or three-blade machine can produce the high rpm (revolutions per minute) suitable for electricity generation.

  [Note:] Because of their visual domination of the landscape, the use of wind turbines is controversial. They may also interfere with the bird life around the field station.

Hybrid systems

Because of the intermittent availability of renewable energy sources, i.e., wind and solar radiation, it is recommended to build a hybrid on-site power generation system for field stations that are off-the-grid and located in remote areas. Hybrid wind-solar systems should increase the reliability of the system. Depending on the characteristics of the local climate, high wind speeds may not coincide with high solar intensities, which increases the probability of meeting the demand in a complete cycle of operation, i.e., one full year.

The downside of hybrid systems is the high initial cost of building two systems for the same facility.

Hydropower

Hydroelectric power generation is the least polluting and least expensive energy source. Hydropower is typically less expensive than fossil fuel-generated electricity. In the rare cases when the field station is located in proximity to a water fall or a continuously flowing stream of water, hydropower can be an option. Even small dams may disrupt biological life in the area, but the use of waterwheels is possible. Waterwheels are the old-fashioned, large diameter, slow-turning devices that are driven by the force of flowing water. They typically need to be housed inside a structure or otherwise protected against freezing in cold climates if year-round operation is required. Dams are not necessary for small-scale hydro systems.

Geothermal

In rare cases when the field station is built in proximity to geothermal wells, the earth's high temperature can be utilized as a renewable free source of energy. Hot water or steam reservoirs deep in the earth can be accessed by drilling. This heat can be used directly to heat buildings, or to drive turbines and generate electricity.

Energy storage

One disadvantage of complete reliance on renewable energy sources is the fact that their availability is intermittent. Sky conditions and wind speeds are uncontrollable and unpredictable. The demand for electricity in the facility may or may not coincide with wind or maximum solar radiation. In the case of an off-the-grid sustainable facility, energy storage is necessary. DC batteries used to store energy add to the overall cost of the system and cause further energy losses.

ENERGY STORAGE: Batteries store locally generated electricity for later use.

Other energy storage systems are compressed air storage and production of hydrogen by means of water electrolysis. However, these systems are currently still experimental.

If the facility is connected to the utility grid via net metering, there is no need for energy storage, because the energy generated on-site can be supplied to the grid and then used later whenever needed. This process makes renewable energy systems more efficient and less expensive, i.e., economically feasible.

Backup electricity generation

Backup electricity generators may be necessary for field stations, such as in the case of sensitive laboratories. If this is the case, noisy fossil fuel generators are generally the only option. These can be:

- Internal combustion engines.
- Gas turbines.

Special systems for marine stations

For marine stations in remote areas, other possible non-conventional renewable energy sources may include wave and tidal power.
[Note:] Wave and tidal power generation may alter the natural habitat, and can be controversial.

10. Water Conservation / Water Supply

Design Objective

Water is the most precious natural resource for life. Biological field stations (and marine laboratories) may obtain their water supply from a municipal water supply or from on-site water wells. In both cases, water conservation is essential, in order to reduce the use of naturally replenishable water wells or to reduce the cost of municipal water.

Recommendations

Durability

Durability of the water supply system helps reduce maintenance cost, reduce the use of materials, and avoid interruption of the facility operation. Special considerations apply in regions subjected to freezing temperatures:

- To avoid rupture due to freezing in cold winter nights, the main supply pipe should be buried below the frost-line of the climatic region.
- To avoid freezing, supply pipes should not run inside poorly-insulated exterior walls.
- To avoid freezing, outdoor water tanks should be well insulated and/or heated during cold winters.

Fire protection water reserve

If a sprinkler system is installed for the safety and protection of occupants of an off-grid facility, there should be a roof-top water tank, which is properly-sized and located for the operation of the sprinkler system. On the other hand, facilities connected to municipal water supply with sufficient water pressure at the site do not require a water tank.

Low flow plumbing fixtures

Plumbing fixtures should be selected based on their rate of water consumption. Low flow faucets, showerheads, and toilets are already available in the market. Example technologies are described below:

- Aerators add air to the water stream to make the flow feel stronger. Faucet aerators mix air within the water flow in order to maintain the same cleaning effect while consuming less water. Showerheads use similar aerator technology and multiple flow settings to save water.
- Laminar flow faucets conserve water by producing dozens of parallel streams of water, which makes a clear solid-looking water stream with a strong cleaning effect, but without consuming large amounts of water.
- Dual-flush toilets are equipped with a two-button system that allows either light or heavy flushes. Over time, dual-flush toilets tend to average less than 1.2 GPF (gallon per flush) compared to 1.6 GPF for regular low-flow toilets. (Conventional toilets use 3.5 to 5 GPF)
- Pressure-assisted toilets supplement the gravity system with water supply line pressure, compressed air, or a vacuum pump.
- Waterless urinals do not consume water to flush, however they are still odor-free. Waterless urinals reduce the use of water, sewage, and maintenance costs.

Hot water systems

High performance hot water systems can save both water and energy. Related recommendations are as follows:

- During the design of the facility, locate the water heater as close as possible to the hot water fixtures. Shorter pipes to the fixtures reduce heat losses, as well as the wasted not-hot-enough water whenever a fixture is used. Proximity of the heater to the fixtures also eliminates the need for a re-circulating pump.
- Use on-demand water heaters. These tankless water heaters eliminate the standby energy losses that may occur when hot water sits in the tank for a long time.

Greywater use

Greywater from sinks, showers, bathtubs, washing machines and dishwashers accounts for more than half the drainage from residential facilities. Unlike blackwater from toilets or drainage from chemistry labs and similar uses, greywater can be recycled for irrigation, flushing toilets, and exterior washing. Greywater re-use systems can be built on site or purchased as a package.

Rain water collection

Especially in the case of remote field stations, rainwater harvesting may be necessary. Rain water collection techniques provide clean high quality water supply. Water harvesting systems can be custom built on the site or

RAIN WATER COLLECTION: A simple water harvesting technique that saves on irrigation.

purchased as a package. Components of these systems include:

- Catchment area, i.e., the roof of the building. Metal roofs are preferred because they stay cleaner than other roofing systems. Metal roofs, if used, should be lead-free.
- Gutters and leaders that direct the water towards the cistern(s).
- A cistern or cisterns to hold the water.
- A treatment system of filters and/or purifiers.
- Pumps to circulate the water to keep it fresh and to pump the clean water to plumbing fixtures.

Reuse of stormwater

Collected stormwater can be used directly for non-potable uses such as landscape irrigation, toilet and urinal flushing, and custodial uses.

Water-efficient landscaping

Watering the landscape is a major consumer of water supply. To minimize water consumption:

- Use drought-tolerant native plants and turf that do not require additional water.
- When irrigation is necessary, use high-efficiency equipment and/or controllers based on climate or soil-moisture.
- If irrigation is required, use stormwater, greywater, or condensate water for irrigation.

11. Sanitary Systems / Off-Grid Systems

Design Objective

Unless the field station is connected to a municipal sewer system, the facility's sanitary system may be a challenge and/or cause additional construction cost. In this case, the field station must depend on its own private sewage disposal system that does not pollute the environment. The recommendations below describe alternative private sewage disposal systems.

Recommendations

Septic systems

In this case, the building's main drain pipe leads to a septic tank. The building's waste and soil disposal flows by gravity from the building into the septic tank. The tank itself is a watertight underground container made of asphalt-protected metal, clay, poured concrete, concrete blocks, or fiberglass. The tank is sized so as to allow the waste to remain in the tank for at least 16 hours before being displaced by incoming sewage. Inside the tank, anaerobic bacteria dissolve most of the solids. Any remaining solids descend to the bottom of the tank and require periodic cleaning.

SEPTIC SYSTEMS: A main pipe leads to the facility's septic tank.

The remaining liquid effluent from the septic tank is led by closed piping to a drain field or seepage pits, which must be located far enough from:

- The building to avoid unpleasant odors.
- Any on-site water wells used for water supply.
- Any sensitive natural water body such as streams, lakes and estuaries.

Composting and incineration toilets

An alternative of septic systems is the use of composting or incineration toilets. These toilets are for light use and do not require a septic tank. Both types require periodic cleaning.

- Composting toilets connect to a large chamber below the floor where the waste decomposes by aerobic digestion. To prevent odor, a one-way air flow is continuously drawn from the room into the composting chamber and vented out through the roof. This air flow also provides the composing chamber with plenty of oxygen for the digestion process.
- Incineration toilets reduce the waste deposited in the unit to a small volume of ash. An electric heating coil, at the bottom of the unit, accelerates the decomposition of the waste, while a fan or exhaust system rejects odor from the unit to the outside. [Incineration toilets consume electricity and they are less desirable than composting toilets.]

COMPOSTING TOILETS: A toilet that decomposes the waste in a chamber below.

The sewage disposal systems described above are used to dispose human waste. In case the facility should dispose harmful chemicals from laboratories, special attention to be given to the design of the sanitary systems to comply with local and EPA discharge regulations.

12. Materials and Product Selection

Design Objective

Sustainable field stations, like any other building type, consume significant amount of materials that were manufactured using natural resources, e.g., plants, metals, water, and fossil fuels. Embodied energy in the construction materials of a building can equate the energy consumed to operate the same building for up to 10 years. Off gassing from some building and finishing materials may harm occupants' health. When it is within budget, the objective is to select materials and products that consume less of the natural resources and do not harm the environment or the occupants. The material selection criteria are explained below.

GREEN MATERIALS: Bamboo flooring, a fast-growth grass.

Recommendations

Resource efficient materials

In order to minimize the overall environmental impact of the building construction and operation, construction and finishing materials, building supplies, and furniture should be made of:

- Materials with high recycled content, like carpet manufactured out of used carpet and vinyl tiles manufactured out of automobile tires.
- Materials manufactured out of natural, plentiful, or renewable resources, like certified wood or bamboo floors and ceiling tiles.
- Materials manufactured through a highly efficient processes that minimizes waste, water consumption, energy consumption, and pollution.
- Locally available materials that reduce transportation energy consumption.
- Recyclable, reusable or bio-degradable materials.
- Durable materials that last many years without the need for maintenance and/or replacement.

Indoor air quality

Materials used inside buildings should not inflict any harm on its occupants. Keeping the occupants healthy and comfortable is essential to maximize their productivity. In this regard, testing of building materials is provided by third-partly verifiers like GREENSEAL and GREENGUARD. In general finishing materials should:

- Emit minimal and non-toxic chemicals.
- Contain low-VOC and require minimal VOC emitting installation and cleaning.
- Be moisture resistant to minimize the growth of biological contaminants inside the facility.

Furthermore, smoking should be prohibited inside the building.

Another concern regarding the indoor air quality is the prevention of elevated levels of radon inside the facility. Radon is an odorless, tasteless, and invisible gas that causes lung cancer, even with exposure to low levels of the gas. If the facility is built in an area with high levels of naturally occurring radon, compliance with radon-resistant building codes is essential. Radon potential is a result of local geology, aerial radioactivity, soil permeability, and foundation type. Radon maps are available online through the EPA website: www.epa.gov/radon001/zonemap.html#more%20about%20the%20map. However, the EPA also recommends that these maps be supplemented with any available local data in order to further understand and predict the radon potential in a specific site.

Green purchasing

Administration of the facility should adopt a policy to purchase green products, e.g., appliances, supplies, and food.

- Purchase Energy-Star-labeled appliances for use in the facility. Energy-

PREVIOUS PAVING MATERIAL (TOP): Drains runoff without erroding the surrounding soil.

GREEN PURCHASING (BOTTOM): FSC certified wood, harvested at a sustainable rate.

Star devices use less energy to operate.

- Purchase computers and other eligible electronics that are tested to be “Bronze level” or higher according to EPEAT (Electronic Product Environmental Assessment Act).
- Purchase fine paper with post-consumer recycled content, tree-free, or FSC (Forest Stewardship Council) certified. All bathroom paper products can be 100% post-consumer recycled content.
- Purchase local organic food products as possible.

13. Waste Management

Design Objective

Depending on the type of consumables used at the field station, on-site recycling may or may not be possible. For the facility to be sustainable, it should recycle all of its waste. If the facility is able to return all of its waste to the land in an environment-friendly form, then the building would be considered an integral part of the earth’s natural cycles.

ORGANIC WASTE: A typical garden composter.

Recommendations

Organic waste

Returning organic waste to the earth is possible and feasible. Organic waste is bio-degradable and it only takes time to break down to its simple natural elements. On-site composting (biological decomposition) is an environment-friendly method of waste management. The EPA (US Environmental Agency) composting recommendations follow.

NON-ORGANIC WASTE: Collection and recycling.

- What to compost: cardboard rolls, clean paper, coffee grounds and filters, cotton rags, dryer and vacuum cleaner lint, eggshells, fireplace ashes, fruits and vegetables, grass clippings, hair and fur, hay and straw, houseplants, leaves, nut shells, sawdust, shredded newspapers, tea bags, wood chips, wool rags, and yard trimming.
- What not to compost: black walnut tree leaves or twigs (releases substance that might be harmful to plants), coal or coal ash (might contain substances harmful to plants), dairy products like milk, yogurt, butter, and egg yolks, fats, grease, lard, or oils, and meat or fish bones and scraps (create odor problems and attract pests such as rodents and flies), diseased or insect-ridden plants (diseases or insects may survive and be transferred back to other plants), and yard trimmings treated with chemical pesticides.

Non-organic waste

Some products and supplies to the field station may end up as a non-organic waste. This waste may include: glass bottles, plastics, and batteries. For remotely-located field stations, municipal trash collection is usually not available. In this case, administration of the facility should adopt a policy to transport this waste either to the nearest municipality or to the manufacturing plants or distributors of these products where they may be recycled or reused. These products may include:

- Glass bottles, light bulbs, and other glass products.
- Plastic products and wrappings.
- Printer toner cartridges and other electronic devices.
- Metals such as food and beverage cans.

Sorting the waste

For sustainable waste management, sort different types of waste at the source in order to save on the labor cost and to make it possible. Clearly-marked trash and recycling bins are essential to be located as convenient as possible to all occupants.

14. On-Site Transportation

Design Objective

Fuel-powered vehicles emit pollutants that harm the environment, disproportionately when operated over short distances. This pollution invariably poses a negative environmental impact on the environment and the surrounding landscape, thus an alternative type of vehicles should be used.

ON-SITE TRANSPORTATION: An electric vehicle.

Recommendations

Use rechargeable electric vehicles

If financially-feasible, electric cars should be used to transport personnel and tools within the protected landscape. Electric cars are slow and short range, however this should not be a disadvantage when protection of the area around the field station is necessary. For remote stations with off-grid electric supply, the extra demand for recharging vehicles must be taken into account in planning electric supply capacity.

15. Rating Systems

This manual is specifically produced to give recommendations that are specific to the design of sustainable biological field stations and marine laboratories. However, facilities at biological field stations or marine laboratories, like any other building type, can also benefit from non-specific sustainable design recommendations. In addition to the recommendations presented in this manual, architects are strongly encouraged to seek other useful recommendations from the most current green buildings' rating systems, e.g., LEED (Leadership in Energy and Environmental Design), Green Globes, SPIRIT, AIA Top Ten Green measures, and design guides produced by the OBFS (Organization of Biological Field Stations, e.g. the Operations Manual – section on Facilities), ASHRAE (American

Society for Heating, Refrigerating, and Air Conditioning Engineers), DOE (Department of Energy), Rocky Mountain Institute (RMI).

Architects, however, need to be cautious if they implement non-specific recommendations. Most of these recommendations ignore contextual parameters, and may not apply to a specific climatic region, setting, or building type. Architects must implement only applicable recommendations to the design and operation of biological field stations or marine laboratories, and ignore what is not.

LEED - New Construction (LEED-NC) rating system was developed by the US Green Building Council (USGBC) in 1993. Since then, it is the most commonly-used rating system by architects in the US. If the client institution elects to certify the field station as a LEED building, the architect should apply only the relevant credit points and avoid the credit points that are inapplicable, unnecessarily expensive, or counterproductive.

16. Design Decisions based on the LCC Analysis

Design Objective

In contrast to investments in commercial buildings, designing a field station should give much higher priority to reducing the operating cost of the facility. Making design decisions based on the Life Cycle Costing (LCC) is essential. The LCC analysis takes into account all expenses of the construction and operation of the facility over its expected life. These expenses include present and future expanses. Because the future value of money is virtually unknown, the LCC analysis only provides a conditional prediction of future expenses.

Recommendations

To make the LCC analysis as accurate as possible, the analysis should include the cost of all direct and indirect costs. These may include the costs of: design fees and other professional services, construction, energy consumption, water consumption, equipment and appliances, furniture, maintenance cost, regular replacement of equipment parts, pollution clean-up, demolition, and the salvage value of the structure.

E2. FUNDING OPPORTUNITIES AND INCENTIVES

IN MOST CASES, biological field stations and marine laboratories are built with the help of private donations allocated specifically to a certain field station. Besides these generous donations, other sources of funding may also be sought out. Examples are below.

- Funding for the design and planning of field stations and marine laboratories, such as possible funding from the US National Science Foundation (NSF) (program: Improvements in Facilities, Communications, and Equipment at Biological Field Stations and Marine Laboratories-FSML), and from the Kresge Foundation (http://www.kresge.org).
- State funds may be available in a form of low-cost or no-interest loans for energy efficient projects. For a complete state-by-state listing, refer to: www.ase.org/content/article/detail/2601
- State rebates for energy efficiency and/or renewable energy generation. For example, in the State of California funding is available for green buildings in a form of rebates for the cost of installed PV (Photovoltaic) systems.
- Local utility companies may also offer energy-efficiency rebates. Utility energy-efficiency rebates are given as incentives for purchasing or upgrading lighting, air conditioning, refrigeration, agricultural equipment, water heating systems, and motors.
- Federal and state tax incentives that may apply to sales, income, and property taxes. For example, many states offer tax credits and/or deductions for cost associated with increased energy efficiency. The 2005 Energy Policy Act offer tax breaks for energy efficiency. Tax incentives are usually authorized for a certain number of years, after which they expire. Of course, tax incentives do not benefit tax-exempt not-for-profit research institutions.

E3. ARCHITECT SELECTION

DESIGN OF A SUSTAINABLE FIELD STATION is an atypical job. It requires a design team that is willing and committed to an unusual task. To be successful, the research institution must find the right designer for the project. The selected architect should show an experience in or promise for designing sustainable buildings. As recommended in the OBFS Operations Manual (section on Facilities), facility planning requires personnel with appropriate skills and experience. Our survey of two of the most successful sustainable field stations supports the same recommendation. Facilities designed for the Jasper Ridge Biological Preserve and Black Rock Forest Consortium were designed by award-winning green designers, architects and engineers.

Indeed, of a paramount importance to a successful design is the representatives of the research institution who interact with the architect are passionate to design a sustainable field station, and for environmental sustainability as a whole.

We also recommend that this manual should be distributed to candidate architects at the beginning of the architect selection process.

E4. PERFORMANCE-BASED CONTRACTS

IN THE US, it is typical for the design fees to be calculated as a percentage of the construction cost of the facility. This tradition is simplistic and does not offer an incentive to the design team to design a sustainable building. For the same program, a sustainable facility may mean: smaller building, efficient structure, and smaller mechanical, electrical, and plumbing systems, i.e., a less expensive building in the overall. In contrast, performance-based contracts link the professional fees to how efficient the building is. The higher efficiency is, the higher the fees. Performance-based contracts encourage designers to be innovative and to find cost-effective ways to make the building more efficient and more sustainable.

Performance-based contracts are outcome-oriented contracts and they require a definition of a standard similar-use building to be considered as the baseline for comparison and to calculate savings. The establishment of this baseline should be negotiated between representatives of the research institution and the design team. Here, it is worth mentioning that the EPA (US Environmental Protection Agency) maintains a database on average performance of a variety of building types in US climates. The EPA Target Finder is accessible online on this web address: www.energystar.gov/index.cfm?c=new_bldg_design.bus_target_finder

As a general recommendation, one should select contractors who have demonstrated experience in these sustainable building elements. If they are the lowest bidder, they probably will have to be educated at every step by the field station administrator. It is far more effective to select contractors who already understand sustainable building design and construction and who already deal with vendors of what are often non-traditional materials (eg. waterless urinals, high performance glazing, etc.)

E5. SITE WORK DURING CONSTRUCTION

IN ORDER TO MAINTAIN the natural balance in the site, it is important that the construction of the planned facility has minimal disturbance of the local environment. The contract with the construction company should include specific enforceable provisions to reduce pollution from construction activities such as:

- Controlling soil erosion, waterway sedimentation, and airborne dust

generation.
- Topsoil and vegetation protection and reuse.
- Hazardous material management.
- Non-invasive construction equipment operation and parking.
- Post construction site cleaning and restoration.

E6. COMMISSIONING AND QUALITY CONTROL

THIRD-PARTY REVIEW of the technical design, predicted savings, and quality of construction is essential to verify the quality of services rendered by the design team and the contractor. Client research institutions may commission this service to an independent third-party that does not hold any professional services or construction contracts with the institution, the design team, or the contractor.

Commissioning adds extra cost to building construction, but is an effective means to assure the quality of the building and its future performance. Commissioning ensures that building systems are designed, installed, tested, and verified as being capable of operating according to the facility's needs and the designer's intent. The commissioning agencies may perform the following tasks:

- Design review of the project at the end of the schematic design.
- Review the design of building systems, especially the HVAC design. Other systems may include: fire safety, emergency power supply, security systems, lab exhaust systems, energy management, data networks, electrical and lighting systems, and kitchen equipment and fume hoods.
- Verify the building performance within the first year of occupancy after substantial completion of the facility.
- Write a final report documenting the final results and recommendations.

JASPER RIDGE: View from the countryside.

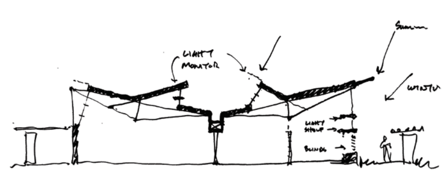
F. CASE STUDY FIELD STATIONS

F1. JASPER RIDGE BIOLOGICAL PRESERVE

WHEN DIRECTOR PHILIPPE COHEN of Jasper Ridge Biological Preserve began lobbying for a new field station facility, his on-site office was an Isuzu Trooper and a small trailer. The 12,000-acre (4856 hectares) preserve, nestled in the foothills of the Santa Cruz Mountains in central California, had only a few hodgepodge facilities: bathhouses, a hamburger stand, a caretaker's cottage, and a few temporary buildings which housed everything from docents to laboratories.[1] The preserve needed new facilities, and in the late 1990s, Anthony Sun gave the lead gift of $3.3 million in memory of his wife, Leslie, who had been a docent at the preserve.

In June of 2002, the Leslie Shao-ming Sun Field Station facility opened as one of the most publicly acclaimed projects in the region, receiving the first San Mateo Country Green Building Award that same year. The success of its sustainable features continued to be recognized when the facility was named one of the Top Ten Green Projects by the American Institute of Architects in 2005.[2] The result was one of the most successful green projects in recent history and one of the most sustainable biological field station facilities in the nation.

SECTION: Initial sketches in section showed an interest in daylighting, drainage, and structure.



1. "An Environmentally Sustainable Field Station at Stanford University," under "Background"; Wilson, Alex. "Green Building: A Natural for This Biological Preserve." Solar Today (Boulder, CO: SOLAR TODAY magazine, 2003) 61.

2. "Commercial Green Buildings." <http://www.sustainablesanmateo.org/?s=leslie+shao-ming&x=0&y=0>. American Institute of Architects. Under "AIA/COTE 2007 Top Ten Awards" (April 25, 2005) <http://www.aiatopten.org/hpb/overview.cfm?ProjectID=457>. (accessed November 06, 2007)

Preliminary design concerns

SKYLIGHT: Daylights the laboratories.

The Jasper Ridge Biological Preserve has been a wonderful example of Stanford's commitment to the environment. A 12,000-acre (4856 hectares) preserve directly adjacent to Silicon Valley is bound to come under pressure by developers, but the size of the preserve is necessary to encourage biodiversity. Despite its incredible economic power, Stanford has always refused to sell it. Accordingly, the land is not a place to have a picnic or play a soccer game; it is used to see how to best manage the earth, analyzing the environment and humanity's impact on it.

It became readily apparent that there is an inherent contradiction for facilities to be built in the very habitats the scientists are studying. Furthermore, not only is Jasper Ridge recognized as an international biosphere preserve, one of its largest research projects is the Jasper Ridge Global Change Experiment.[3] If the building that was to be built contributed to the very problems the research was trying to solve, the message sent to the thousands of annual visitors would be very mixed. For these reasons, the first concern for Cohen and the staff of Jasper Ridge was that the building would be as environment-friendly as possible. The staff even specified that the building have net zero carbon emissions.

LABORATORIES: Evenly daylit with windows, clerestory, and skylights.

The selection of the architecture firm was critical for the success of the project. Stanford's campus architect provided Cohen with a list of architects, and an extensive interview process followed. After these interviews, the firm Rob Wellington Quigley, FAIA was selected. With offices out of San Diego and Palo Alto, they were a local firm who knew the climate and area well, with a rich history of designing buildings with a social conscience. In 1992 the AIAS awarded Quigley's firm the National Honor Award for their 202 Island Inn, a HUD-subsidized hotel, providing housing for those with low-income and nowhere else to go. The resulting design was a beautifully contextual hotel with exuberance and color. With so much of contemporary architecture being nothing more than an expression of the architect's own egotism, finding an architect with a solid sense of reality, social awareness, and humility is unquestionably helpful in the design process. Quigley points out that, "Architecture is distinguished from the fine arts not just because of its public utility, but because of the collaborative nature of the creative process."[4]

The next step in the design process was the site selection. After an overview of the available sites was conducted, a few factors took precedence. The selected site allowed for good solar access and an east-to-west orientation that would maximize the harnessing of solar energy. Perhaps most importantly, the building could not disrupt the habitat. To minimize impact, a site was chosen that already had access to parking and utilities, and the

3. Orion, Tamsin (Director). "Jasper Ridge: An Island of Discovery." Video retrieved on October 25, 2007. <http://vodreal.stanford.edu/Jasper/island.ram>.

4. Rob Wellington Quigley, FAIA. Rob Wellington Quigley: Buildings + Projects (New York: Rizzoli International Publications, 1996) 7.

selected site posed no risk to Jasper Ridge archeological sites. Views from the surrounding hills were taken into account in order to preserve the beauty of the landscape.

Systems and energy use

The Leslie Shao-ming Sun Field Station facility reduces energy use in a variety of ways. In addition to maximizing solar exposure the architects harnessed this energy in several ways: daylighting, active solar heating and cooling, and solar panels.

WORKERS: Volunteers with recycled materials.

One of the most successful features is the natural daylighting of the labs and other interior spaces. Large, iconic glass windows face to the south, and light monitors in the roof provide diffuse light to meet the needs for task lighting during the day. Yet this revealed an inherent contradiction that exists between many sustainability measures. After a scale model of the building was taken to the San Francisco's PG&E Energy Center and tested on a Heliodon, the design team discovered that there was too much glare in the laboratory spaces. Adequate solar gain for passive heating let too much light in for comfortable daylighting. The research work done in the labs and the comfortable lighting conditions they would require took precedence over a passive system, so an active heating system was developed instead. Due to the intensive study of daylighting conditions, a nearly even spread of light exists from the south end to the north end of the building.[5]

The transition between systems is seamless. Directly above the windows are large solar collectors which heat a water tank inside. When colder weather arrives, this heat can be pumped into wall radiators. The pitch of the collectors also doubles as a shading device for the south facing glass. In this way, the building satisfies both the need for natural daylighting and space heating. The heating system has been quite successful, providing 60-80% of the total energy use for heating the facility in wintertime.

The passive cooling system for Jasper Ridge is just as impressive. 90% of the building is passively cooled, with only the herbarium being provided with an AC. This is achieved with Heat Mirror® glazing from Southwall Technology, high-performance glazing that eliminates incoming heat while transmitting daylight; insulation on the roof to reduce thermal loss; and operable windows for natural ventilation in all occupied spaces.

The photovoltaic cells are mounted on the butterfly roof. This 22-kilowatt (kW) system is connected to the grid; when net energy is produced, it is sent back to the grid. The panels are grouped together into sub-arrays that have different orientations and pitches. This allows for comparative data and for the researchers to find the best orientation and pitch to collect light from the sun.

5. Wilson, Alex. "Green Building: A Natural for This Biological Preserve." Solar Today (Boulder, CO: SOLAR TODAY magazine, 2003) 62.

Green materials

A beautiful attribute of the Sun Field Station facility is how it makes recycling more than an ethic: it becomes an aesthetic. Fly ash concrete was used instead of the traditional Portland cement. Fly ash is a mineral residue from coal-fired power plants, which is responsible for about 8% of global carbon emissions. Cement use can be greatly reduced by using high fly ash concrete instead. This prevents the associated CO2 emissions, as well as reuses a product that would normally find its way to a landfill.

The building's siding and paving were also recycled, this time directly from Stanford University. In the 1880s, brick was brought as ship ballast from Scotland, and then used in the basement of Leland and Jane Stanford's campus home. This brick was used as paving for the two entrances to the station.[6] The building's beautiful redwood siding was recycled from a building in Woodside, CA and Escondido Village.[7]

MATERIALS: Fly ash concrete and FSC approved lumber.

All the necessary lumber that could not be salvaged from existing buildings was approved by the Forest Stewardship Council (FSC). The FSC is a non-profit organization that, according to their own mission, aims to "promote environmentally appropriate, socially beneficial, and economically viable management of the world's forests."[8] In this particular case, the approved lumber came from the nearby forests in Mendocino County, where the forestry operations are certified as sustainable.

Unoccupied campus buildings provided the casework and much of the furnishings for the facility. Recycled newsprint was used for wall insulation, while the 1902 "Old Chem" building on Stanford's campus provided the bathroom partitions, and no materials with VOCs (volatile organic compounds), which can contribute to indoor air pollution problems like sick building syndrome, were used inside the building.

Structure

All good design is a synthesis of factors, and the Sun Field Station facility proved that a single, powerful vision could bring those jumbled parts together. Yet in the integration process, the structural system of a building is often ignored by architects and clients alike. The ingenuity of Jasper Ridge is how an efficient structural system began to define other features of the building, like its ability collect rainwater and maximize daylighting.

The initial scheme to invert the roof was a structural innovation on the part of Paul Endres of Endres Ware Architects Engineers, a unique Berkeley firm dedicated to bridging "the traditional boundaries between architecture

TRUSS: A reversed truss roof system with composite wood trusses and steel cables.

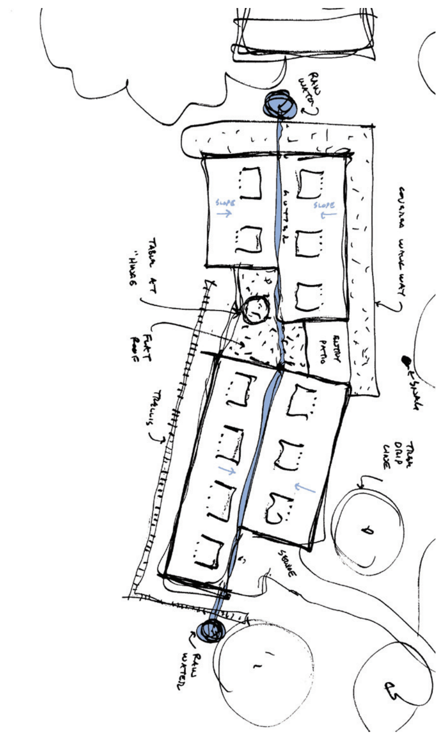
6. Wilson, Alex. "Green Building: A Natural for This Biological Preserve." Solar Today (Boulder, CO: SOLAR TODAY magazine, 2003) 62.

7. Eule, Brian. "Not Easy Being Green? Check out Jasper Ridge." Stanford Magazine, 2003.

8. Forest Stewardship Council. Under "About FSC / Mission." (1996) <http://www.fsc.org/en/about/about_fsc/mission> (accessed October 3, 2007).

and engineering."[9] Mr. Endres proposed a reversed truss roof system with composite steel cables and wood trusses (imagine a typical A-frame truss now upside down) under a butterfly roof; this would maximize the height of the windows to the south while creating a channel to collect rainwater. Cohen was unconvinced until Endres revealed a homemade imitation of the truss, placed it between two chairs, and had the director walk across the mock-up bridge. Convinced that the system would be stable, and not leak, Cohen gave his approval.

The structural system also allows for fewer materials. By cantilevering the ends of the truss on columns instead of load-bearing walls, the engineers were able to create a floor space that required no interior partitions.



SKETCH: Conceptual sketch/floorplan.

Other sustainable features

With potable water consumption being as high as it is with buildings, the Sun Field Station facility made responsible water use another main concern. The building operates on two levels: water reduction and water collection. Water use was reduced by simple but effective means, such as efficient fixtures and waterless urinals (which can reduce water use by 40%[10]) and a gas-fired tankless water heater. As mentioned in the previous section, the butterfly roof doubled as a collector for rainwater. This empties into a 25,000 gallon cistern, storing water for later use, notably for irrigation. Other features include: a recycling system that was constructed by a sanitation company, Energy Star approved appliances, and native landscaping.[11] As a whole, the sustainable features work together to provide the best solution for Jasper Ridge Biological Preserve's new field station.

Cost and performance

The best part about the Leslie Shao-ming Sun Field Station facility is simple: it works. Having a plethora of sustainable features at exorbitant prices is no more laudable than being environmentally irresponsible. At $249 per square foot in California's high-end economy, the station settles in quite nicely, especially when compared to other facilities in the region. What makes the Sun Field Station facility so tantalizing as a case study is that it's performance and cost-efficiency is provable. For example, comparing the price per square foot of field stations would mean very little. With different economics, climates, and time periods, it would be a difficult task to say which field stations are truly the most economical. However, Stanford also built two other buildings on campus at the price of $240 per square foot and $223 per square foot.[12]

JASPER RIDGE: Back of the Shao-ming Sun Field Station.

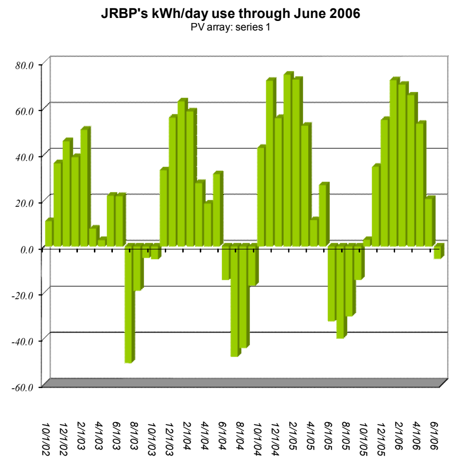
9. Endres Ware Architects Engineers. "Studio." (November 9, 2006), <http://www.endresware.com/studio.htm> (accessed November 3, 2007).

10. Todd, H. Ruth. Conference Abstract (presented at a meeting for An Environmentally Sustainable Field Station for Stanford University's Jasper Ridge Biological Preserve) 2.

11. Cohen, Philippe. 2007. Questionnaire by Gregory Gundersen

12. Ibid.

This comparison is useful, because it provides the constants of local economy, climate, and time. Factors like construction cost or the necessary HVAC for a building should be so similar as to be negligible in a comparison. The sustainable building has much more economical operating costs, as it produces all or nearly all of its energy consumption each month, at a very reasonable initial price.



Furthermore, the performance of the building has been constantly monitored since nearly a year after the station was completed, and the feedback data have been all positive.[13] For example, the twenty-six 4'x8' Heliodyne solar thermal collector panels heat the entire building except for blowers in the classroom, which give rapid heating. All these features are connected to the photovoltaic system for energy use. The success can be measured simply: lights were not needed during the day for the first three months after occupation.

The investment in solar panels was not as burdensome as it might have been; the state of California subsidized the system with $80,000. With this kind of initiative and intelligent thinking on the part of both Cohen and Quigley, the Jasper Ridge Biological Preserve was able to build a fantastic facility at a reasonable cost.

The effectiveness of these solutions has been widely recognized on regional and national levels, and Stanford made the facility a model for future sustainable buildings on campus. In conclusion, the Leslie Shao-ming Sun Field Station facility has proven that sustainability can provide holistic, beautiful solutions that protect the environment while remaining economical and effective.

With dedication to work together, Philippe Cohen, the facility's staff and scientists, and Rob Wellington Quigley, FAIA were able to create the best possible solution without compromising the architectural complexity and relevance of the work.

Awards for the Leslie-Shao Ming Sun Field Station

2005 / AIA National / Committee on the Environment Top Ten Green Buildings

2004 / AIA Santa Clara Valley / Honor Award

2003 / AIA San Diego / Merit Award

2003 / San Mateo County / Recycleworks Green Building Award
Award for Engineering Excellence to Dagher Engineering PLLC for the Forest Lodge's geothermal heat pump.

13. Ibid.

THE FOREST LODGE: Autumn view.

F2. BLACK ROCK FOREST CONSORTIUM

LOCATED IN NEW YORK'S HUDSON HIGHLANDS, the Black Rock Forest Consortium is 3830-acres (1550 hectares) of preserved forest for research and education. Purchased from Harvard University in 1989 by William T. Golden, the Forest was leased to the Consortium, a group of local universities who were interested in sharing operating costs and using the land for research but did not have the funds to buy the land.[1]

In 1995 the Black Rock Forest Consortium considered building their first permanent structures for the preserve. To help develop a master plan and design two new facilities, the Consortium interviewed several leading New York City firms and chose Fox & Fowle Architects (now FXFOWLE ARCHITECTS, PC) due to their willingness to listen and commitment to sustainable design. According to Forest's director, Dr. William Schuster, "We were jointly, fully committed to making our building as 'green' as possible."[2] The master plan incorporated two designs: the Center for Science and Education (Phase I, completed in 1999) and the Forest Lodge (Phase II, completed in 2004).

Preliminary design concerns

After extensive review of the preserve, a site was chosen atop Whitehorse Mountain. The site was selected near an old farm and roadway; the choice was based on a number of criteria, such as ease of utility connections, safe and pre-existing vehicular access along with easy foot access to the Forest, low biodiversity, and the obvious benefits of using a previously disturbed

CENTER FOR SCIENCE & EDUCTION (BELOW): North façade with smaller windows.

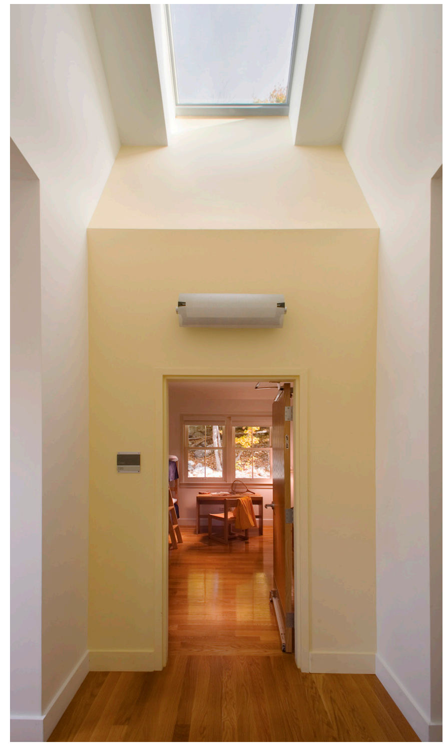
BOTTOM: South façade with larger windows and direct solar exposure.

1. Black Rock Forest Consortium. Under "The Forest / Forest History." (October 25, 2007). <http://www.blackrockforest.org/docs/about-the-forest/the-forest/ForestHistory.html> (accessed November 05, 2007).

2. Schuster, William. 2007. Questionnaire by Gregory Gundersen.

site.[3] The aesthetics of the site were also unparalleled, with a beautiful and quiet environment that was a good distance from surrounding neighbors.

The first of the two buildings, the Center for Science and Education, was situated on the shoulder of Whitehorse Mountain to maximize views and solar access while avoiding local bedrock; the building's rectangular plan and east-to-west orientation help in this by minimizing the building's mass and envelope and accessing southern daylight. The Forest Lodge faces southwest and is situated in a "natural bench" next to the roadway. As a whole, the buildings create a comfortable campus feel and possess wonderful views of the Forest.



FOREST LODGE: Skylights illuminate the central hallway.

Systems and energy use

Phase I, the Center for Science and Education, achieved energy efficiency by a combination of several effective measures. The primary active system for heating and cooling is a geothermal heat pump, a system for heating and cooling that uses the earth's thermal mass as a heat exchanger. A thermal transfer fluid, typically water, is pumped through pipes embedded beneath the frost line where the earth can be used as a heat source for heating and as a heat sink for cooling. The benefits from this simple system are immense; according to the EPA, "GeoExchange systems are the most energy-efficient, environmentally clean, and cost-effective space conditioning systems available."[4]

The Center's envelope was well-insulated, and the roof was built with structural insulated panels (SIPS). Finally, the windows were sized according to their orientation. North-facing windows are fewer in number. Since glass has no insulation R-value—the measure of a material's resistance to heating flowing through it—this greatly reduces infiltration in cold Mid-Atlantic winters. The southern glass, on the other hand, was sized to allow for passive heating in the winter. This heat gain, which would be detrimental in the summer, is reduced by window overhangs.

CENTER FOR SCIENCE & EDUCATION: Atrium with light monitor and timber columns.

Natural daylight is accessed by a roof monitor, a gable raised above the two-story atrium that visually and physically organizes the Center. This raised gable provides clerestory lighting with operable windows. Besides the flood of light that is welcomed into the atrium, the light monitor's operable windows and fan provide natural ventilation in the warm summers.

For phase II, the Forest Lodge's insulation, daylighting, heating, and cooling were considered in much the same way as the Center. SIPS were used in the roof, and the walls were insulated with dense-pack cellulose. A light monitor once again organizes the space, this time resting above a glassed gathering space. Clerestory lighting with operable windows and

3. Gould, Kira L. Fox & Fowle: Designing the Built Realm (Mulgrave, Vic.: Images Publishing Dist A/C, 2006)

4. U.S. Environmental Protection Agency. Space Conditioning: The Next Frontier, 430-R-93-004 (1993).

fans provide natural ventilation. A unique feature is that the central hallway running to the sleeping rooms is daylit with skylights along the roof's spine. A geothermal heat pump was designed by Dagher Engineering PLLC. The heat pump systems for the Center and Lodge were quite successful; in 2005 the American Council for Engineering Companies of New York awarded Dagher Engineering their Gold Award for Engineering Excellence for the Forest Lodge's geothermal heat pump.[5]

CENTER FOR SCIENCE & EDUCATION: Local red oak integrated into the structural system.

Green materials

FXFOWLE took a unique approach to material usage in the Center and the Lodge. Besides designing a well-organized layout for efficient material use and local and recycled materials whenever possible, both buildings embrace the forest in very tangible ways. Many building materials were chosen directly from the Forest. The four columns flanking the Center's atrium and supporting the staircases on the north façade were all selected from the Forest. The metaphor was that of a "clearing in the forest." Wainscoting was harvested from local red oak, and rocks carefully and painstakingly taken from the Forest were used on the basement levels of the buildings' exterior facades.

This brings to head an important quality of truly sustainable design: buildings that are green are also psychologically green. Conserving energy and saving money are both important, but fostering an appreciation for the environment is the true source of inspiration. By flooding the Center's atrium with light and using tree trunks, the researchers, scientists, and students are given a better quality of life, one that respects and embraces the world around them.

Cost and performance

The green campus for the Black Rock Forest Consortium showcases how quality green architecture can save on energy while providing beautiful facilities that blend with the natural environment. While green architecture often has negative connotations of looking high-tech or esoteric, the Center for Science and Education and the Forest Lodge are both traditional, New England structures, complete with vernacular gables, bevel siding, and stone-clad basements.

The final cost and performance of the facilities were quite reasonable. The Center for Science and Education cost approximately $200 per square foot and the Forest Lodge was $250 per square foot. Not only was this cost average for comparable buildings in the region, the costs paid for themselves with energy bills that were considerably less than comparable buildings. Proper insulation helped maintain desired building temperature, and advances such a geothermal heat pump, photovoltaic array, and

5. Black Rock Forest Consortium. "Green Building and Smart Features: Awards." (October 25, 2007) <http://www.blackrockforest.org/docs/about-the-forest/GreenBuildings/Awards.html>. (accessed November 05, 2007)

daylighting reduced the net energy use. A computer-modeled energy consumption analysis of the Center for Science and Education concluded that it "consumes 45 percent less energy annually compared to a traditional structure meeting all applicable codes."

Awards for the Center for Science and Education and the Forest Lodge

2004 / Northeast Sustainable Energy Association / Honorable mention in the Northeast Green Building Awards

2002 / Design Share / School Construction News Design Share Honor Award

2002 / Orange Environment / Orange Environment's 2002 Environmental Education Award

2005 / American Council for Engineering Companies of New York / Gold

APPENDIX 1. CURRENT TRENDS IN THE DESIGN OF FIELD STATIONS

In the fall of 2006, a questionnaire was sent to biological field stations across the United States (and a few outside) to gather first impressions: what kind of sustainable features were being used, who was using them, what were the barriers?, etc. The questionnaire was a bit naïve—and perhaps poorly constructed—in trying to quantify or tabulate many of the results, but it was a strong impetus regardless: few field stations had any sustainable measures to speak of. So while the data pool for these survey results is small, it reflects how few field stations in the United States are even sustainable.

The most useful and quantifiable results are shown below. In table 1, the frequency of using particular measures is tabulated. Reasons for these selections were most often based on cost, efficiency, ease of installation, and ease of upkeep. In table 2, the most sustainable field stations are tabulated. Field stations are named by location. In particular, the graph shows patterns of use: if a field station can only use one sustainable measure, which one have they chosen? What do the most sustainable all do?

Tables 1 and 2 are shown on the next page.

Table 1: Frequency of Use

Sustainable Strategy	Frequency of Use										
Photovoltaic Cells	■	■	■	■	■	■	■	■	■	■	
Water collection	■	■	■	■	■	■	■	■	■		
Water storage system	■	■	■	■	■	■	■	■			
Insulation	■	■	■	■	■	■	■				
Site Selection	■	■	■	■	■	■					
Passive Cooling	■	■	■	■	■	■					
Local Materials	■	■	■	■	■						
Efficient HVAC	■	■	■	■	■						
Water-conserving Appliances	■	■	■	■	■						
Low-Emission Materials	■	■	■	■							
Passive Heating	■	■	■	■							
Green Appliances	■	■	■	■							
Construction Management	■	■	■								
Building Orientation	■	■	■								
Recycled Materials	■	■	■								
Renewable Materials	■	■	■								
Daylighting	■	■	■								
Computer-monitored HVAC	■	■	■								
Heat Recovery Systems	■										
Landscaping	■										

Table 2: Most Sustainable Field Stations

Biological Field Station	Site Selection	Construction Management	Building Orientation	Photovoltaic Cells	Local Materials	Recycled Materials	Renewable Materials	Low-Emission Materials	Insulation	Passive Heating	Heat Recovery Systems	Passive Cooling	Efficient HVAC	Daylighting	Green Appliances	Computer-monitored HVAC	Water-conserving Appliances	Water collection	Water storage system	Landscaping
Southwest, Standford, CA	■	■	■	■	■	■	■	■	■	■		■		■	■	■	■	■	■	
Northeast, Cornell, NY	■	■	■		■	■	■	■	■	■		■	■	■	■	■	■	■		■
North, Hastings, MI	■			■			■	■	■	■		■	■							
Northeast, Huntingdon, PA	■				■	■				■		■		■			■	■	■	
Central America, Belmopan, Belize	■	■		■								■			■		■	■	■	
Southwest, Oakland, CA	■		■	■					■			■					■	■	■	
North, Notre Dame, IN									■		■		■			■				
Midwest, Corpus Cristi, TX				■											■			■	■	
Northwest, Bozeman, MT					■			■	■											
Southeast, Lake Placid, FL																		■	■	
Midwest, El Paso, TX				■	■															
Southwest, Berkeley, CA				■																
North, Macomb, IL									■											
North, Oxford, OH				■																

GLOSSARY

AIA: the American Institute of Architects, which is the professional association of licensed architects in the US. The AIA mission is to improve the quality of the built environment. The AIA-COTE (Committee on the Environment) is actively involved in and promoting the design of sustainable/green buildings.

Air exfiltration: is the leakage of conditioned air from inside buildings to the outside due to difference in pressure.

Air infiltration: is the leakage of outside air to the interior spaces in buildings due to difference in pressure. Both infiltration and exfiltration happen through cracks in the envelope, i.e., cracks around windows and exterior doors.

ASHRAE: is the American Society of Heating, Refrigerating and Air-Conditioning Engineers, which is an international technical society organized to advance the arts and sciences of heating, ventilation, air-conditioning and refrigeration. ASHRAE develops technical guides and standards that address energy consumption in buildings. ASHRAE standards are normally adopted by the International Building Code.

Building systems: are the engineered systems that are designed to meet a certain need in the operation of a building, such as, air-conditioning, fire-protection, electrical, lighting, signal, conveying, and plumbing systems.

Commissioning: building commissioning is the third-party verification and documentation that building systems function according to criteria set forth in the project documents to satisfy the owner's operational needs. This verification process takes place after the completion of the construction of buildings. It should not be undertaken by the building designer or the contractor.

Cooling load: is the total amount of heat (per time) that must be removed from a space or a building to maintain its temperature at a certain level/setpoint. Cooling load is the result of heat gain added to the interior spaces in buildings.

Cooling season: is the time duration in the year, in which the building requires cooling. The length of the cooling season depends in the micro-climatic conditions at the building site.

COP: Coefficient of Performance of a heat pump is the dimensionless ratio of heat produced (or transported) to the energy supplied.

DOE: is the U.S. Department of Energy. Among many responsibilities, DOE provides support and funding for energy conservation programs.

Economizer cycle: is the operation of the HVAC system to use cool outside air for the cooling of indoor spaces. This mode of operation saves energy in cold and temperate climates, and improved the indoor air quality. It may not be appropriate in hot and humid climates.

EPA: is the U.S. Environmental Protection Agency. EPA's goals include: clean air, clean and safe water, water management, and pollution prevention. EPA administers the Energy Star program, which promotes energy efficient products, including buildings.

FIREWISE: the national Firewise Communities program is intended to serve a resource for agencies, tribes, organizations, fire departments, and communities across the U.S. who are working toward a common goal: reduce loss of lives, property, and resources to wildland fire by building and maintaining communities in a way that is compatible with our natural surroundings.

Gray water: is the wastewater from domestic processes such as washing dishes, bathing and washing machines. Gray water is not heavily polluted with chemicals or biological contaminants.

Green roofs: are roofs (of buildings) with plants growing on them. These roofs can be accessible for use or inaccessible.

Heat recovery: is the process of recovering the heat energy from the exhaust air and transfer it to the fresh air as it enters the HVAC system. A heat recovery unit is usually an air-to-air heat exchanger. An energy recovery unit can be a rotating wheel that can transfer both heat and humidity.

Heating load: is the total amount of heat (per time) that must be added to a space or a building to maintain its temperature at a certain level/setpoint. Heating load is the result of heat loss from the interior spaces in buildings.

Heating season: is the time duration in the year, in which the building requires heating. The length of the heating season depends in the micro-climatic conditions at the building site.

Hectare: is a metric unit to measure area. One hectare equals 2.471 acres.

Heliodon: is a device to simulate the sun position in the sky (horizontal and vertical angles) and its relative position to buildings. It is usually used by architects to perform solar studies.

HVAC: is the mechanical system for Heating, Ventilation and Air-Conditioning of buildings.

IECC: is the International Energy Conservation Code, which is part of the International Building Code (IBC).

Integrated Design Process: is a holistic approach of design that emphasizes the integration of interdisciplinary knowledge throughout the design process; from the early schematic design phase till the end of the preparation of the construction documents for a new project. Design of sustainable buildings requires close collaboration between all design professionals.

LEED certification: LEED is a rating system for sustainable buildings. It is developed by the U.S. Green Building Council (USGBC). A building qualifies for LEED certification when it achieves a certain number of credit points of the LEED checklist. In LEED-NC 2.2 (2008), out of 69 possible credit points, 26 points entail certification; 33 points entail silver rating, 39 points entail gold rating, and 52 points entail platinum rating.

Outside air load: is either the heat added to or removed from a conditioned indoor space due to using the fresh outside air for ventilation.

Plate-to-plate heat recovery: is a heat exchanger that is designed to transfer heat between two streams of air across metal plates with large surface area separating the two streams.

Point of diminishing return: the point of diminishing return is the point after which, the cost of investment becomes higher than the expected savings. In the case of building performance, the point of diminishing return determines the extent of cost-effective investment in energy-conserving measures, after which any investment in upgrades does not make financial sense.

Refrigeration cycle: is a thermodynamic process in which mechanical work is consumed to transfer the heat against the direction of its natural flow, i.e., from a lower to a higher temperature resulting in a cooling effect at the lower temperature.

RMI: the Rocky Mountain Institute is a nonprofit organization that fosters the efficient and restorative use of natural resources. It carries out significant research projects on sustainable buildings.

Roof pond: is a passive system that can help cool the building in the summer and heat it in winter. A roof pond consists of water containers located on the roof of a building. In the heating mode, the water can absorb solar heat during the day and then release it to the building during the night. In the cooling mode, the water can absorb heat from the building and then radiate it to the dark sky during the night.

Solarium: is a south-facing highly-glazed room that collects solar heat (a sunroom).

SPiRiT: is a rating tool for the US Army sustainable buildings. SPiRiT stands for Sustainable Project Rating Tool.

Stormwater: is the water accumulated due to precipitation.

Thermal mass wall: is a wall built of high thermal capacity material, such as, masonry or concrete that can store large amounts of heat for an extended period of time.

Transmitted load: is the heat transmitted through surfaces, such as, opaque walls or glass due to the temperature difference across this surface.

Trombe wall: is a heavy wall that functions as thermal mass exposed to the sun and protected (against cold air) by an air space sandwiched between the wall and insulated glass. Trombe wall is named after the French engineer Felix Trombe who made this system popular in passive solar houses.

U value: is the thermal conductance of a material, which equals to the amount of heat transfer through one unit area of this material in one hour when the temperature difference (between its two sides) equals one degree. In the P-I system, U-value is measured in (Btuh/sq.ft. Fo), and in the metric system, in (W/m2. Co). U-value is also known as the overall heat transfer coefficient, and it is the inverse of R-value (thermal resistance).

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